INTERNATIONAL CRITICAL TABLES
OF
NUMERICAL DATA
PHYSICS, CHEMISTRY AND TECHNOLOGY

VOLUME II

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OF
NUMERICAL DATA,
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INTRODUCTION TO VOLUME II

This volume covers the characteristic properties of a variety of natural and industrial materials and products, together with some additional miscellaneous information of technological interest. Many of the materials treated in this volume are so variable in chemical composition or physical constitution, or both, that no critical evaluation of their properties in the ordinary sense of the term is possible. The values given have, therefore, been selected so as to portray one or all of the following: typical or average values with departures to be expected; maximum and (or) minimum values; range within which the value may be expected to fall; or (in cases where only fragmentary data are available) the values as recorded in the literature. In other cases, such as metals and alloys, commercial glasses, saccharimetry, etc., greater exactness is possible as the materials or substances dealt with have been or can be more or less exactly controlled as to chemical composition and physical condition. In the section on metals and alloys it has been deemed desirable to include most of the industrially important properties of the pure metallic elements. Properties not so included in this section are treated in the succeeding volumes but for completeness are included in the index table on p. 358 of this volume.

Certain topics logically belonging in this volume have had to be omitted owing to failure on the part of the Cooperating Expert to submit his manuscript in time or owing to delays incident to revisions therein required by the Board of Editors. Such topics should be looked for in the appendix to Volume V.

To obviate frequent repetition the definitions of a number of mechanical properties used rather frequently in the volume are brought together on p. viii. Throughout the volume these definitions are cited in the form: "Def. 3," "Def. 16," etc.

In the first edition of a work of this magnitude and complexity errors will necessarily occur, and the Board of Editors will be grateful if the users of the International Critical Tables will call its attention to all errata noted.

DEFINITIONS

1. Proportional Limit.—Stress at which the deformation ceases to be proportional to the load as determined by strainometer (extensometer for tension, compressometer for compression, and deflectometer for transverse tests, value being read from plotted results).

2. Elastic Limit.—In tensile and compressive tests: The stress at which the initial permanent elongation or shortening of the gage length occurs, as shown by an instrument of high precision (determined from set readings with extensometer or compressometer). In transverse tests: The extreme fiber stress at which the initial appreciable permanent deflection occurs as determined with deflectometer.

Tests are rarely made to determine the elastic limit, since such tests involve repeated application and release of load, and require considerable time. For practical purposes the elastic limit may be regarded as equal to the proportional limit.

3. Yield Point.—Stress at which marked increase in deformation of specimen occurs without increase in load as determined usually by drop of beam or with dividers for tensile, compressive, or transverse tests.

4. Tensile, Compressive, or Shearing Strength (Ultimate).—Maximum stress to which the test specimen is subjected by slowly increased load until rupture, divided by the original cross-sectional area of the test specimen.

5. Modulus of Rupture.—Maximum stress in the extreme fiber of a specimen tested to rupture, as computed by the empirical application of the flexural formula to stresses above the transverse proportional limit. For simple rectangular test piece with concentrated center load, it equals

$$\frac{1.5 \times \text{load} \times \text{span}}{\text{area} \times \text{depth}}$$

6. Torsional Strength (or Modulus of Rupture in Torsion).—Maximum stress in the extreme fiber of a specimen tested to rupture as computed by the empirical application of the torsional formula to stresses above the torsional proportional limit. For a round specimen it is

$$S = \frac{5.1 \times \text{twisting moment}}{\text{diameter}^3}$$

In ductile materials the stress at rupture may be considered uniformly distributed over the cross-sectional area and the above formula assumes the form

$$S = \frac{3.82 \times \text{twisting moment}}{\text{diameter}^3}$$

7. Elongation.—The percentage of elongation is found by dividing 100 × the increase of length after rupture by the original gage length. The percentage of elongation depends on the gage length. The elongation indicates the ductility of the material.

8. Reduction of Area.—The percentage of reduction is found as the ratio of 100 × the difference between the original and broken area of cross section to the original area. Reduction of area indicates generally the ductility of material.

9. Poisson's Ratio.—The ratio of lateral contraction per unit of diameter to longitudinal extension per unit of length of a bar under terminal tension within the elastic limit of material.

DEFINITIONS

1. Limite de proportionnalité.—C'est la tension pour laquelle la déformation cesse d'être proportionnelle à la charge, cette tension étant déterminée à l'aide d'un appareil approprié: extensomètre pour la traction, compressomètre pour la compression, et déflectomètre pour les essais de flexion, la valeur de cette tension étant déduite d'une courbe tracée par points.

2. Limite d'élasticité.—Pour les essais de traction et de compression: c'est la plus petite tension pour laquelle la déformation permanente de la longueur entre repères devient appréciable au moyen d'un instrument de haute précision (cette tension étant déterminée au moyen des lectures effectuées à l'aide de l'extensomètre ou du compressomètre). Pour les essais de flexion: c'est la plus petite tension de la fibre extrême, pour laquelle la déformation permanente devient appréciable au moyen du déflectomètre.

Comme la détermination de la limite d'élasticité implique une succession de mises en charge et de décharges de l'éprouvette, et demande un temps considérable, ces essais sont rarement effectués. Dans la pratique on peut considérer la limite d'élasticité comme étant égale à la limite de proportionnalité.

3. Limite d'étirage.—C'est la tension pour laquelle se produit une augmentation importante de la déformation de l'éprouvette sans augmentation de la charge, cette détermination étant faite ordinairement par la chute de l'aiguille ou au compas pour les essais de traction, compression et flexion. (Limite élastique apparente.)

4. Résistance à la traction, à la compression; Résistance au cisaillement.—C'est l'effort maximum auquel l'éprouvette est soumise, par l'augmentation lente et progressive de la charge, jusqu'à rupture, divisé par la section transversale initiale de l'éprouvette.

5. Module de rupture.—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de flexion, à une tension supérieure à la limite de proportionnalité de la flexion. Pour une éprouvette simple de section rectangulaire, avec une charge concentrée au milieu de la portée, elle est égale à:

$$1{,}5 \times \text{charge} \times \text{portée/section} \times \text{hauteur de la pièce}$$

6. Résistance à la torsion (ou module de rupture à la torsion).—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de torsion à une tension supérieure à la limite de proportionnalité de la torsion. Pour une éprouvette de section circulaire, elle est égale à:

$$S = 5{,}1 \times \text{moment de torsion/diamètre}^3$$

Pour les matières ductiles, la tension lors de la rupture peut être considérée comme étant répartie uniformément dans la section transversale et la formule ci-dessus prend la forme:

$$S = 3{,}82 \times \text{moment de torsion/diamètre}^3$$

7. Allongement.—Le pourcentage d'allongement est obtenu en multipliant par 100 le rapport de l'augmentation de la longueur après rupture à la longueur initiale entre repères. Le pourcentage d'allongement dépend de la longueur entre repères. L'allongement donne une mesure de la ductilité de la matière.

8. Striction.—Le pourcentage de striction est le rapport multiplié par 100 de la différence entre la section initiale et la section de rupture à la section initiale. La striction donne généralement une mesure de la ductilité de la matière.

9. Coefficient de Poisson.—C'est le rapport de la contraction transversale (par unité de diamètre) à la dilatation longitudinale

DEFINITIONEN

1. Proportionalitäts-Grenze.—Spannung, bei der die Formänderung aufhört proportional zur Belastung zu verlaufen; sie wird bestimmt durch ein Formänderungsmessinstrument (Dehnungsmesser für Zug, Zusammendrückungsmesser für Druck und Durchbiegungsmesser für Biegeversuche, der Punkt wird aus dem Diagramm ermittelt).

2. Elastizitäts-Grenze.—Bei Zug- und Druckversuchen: Diejenige Spannung bei der die erste bleibende Dehnung oder Verkürzung der Messlänge eintritt, bestimmt durch ein Messinstrument von hoher Präzision (bestimmt aus den Restablesungen am Dehnungs- oder Zusammendrückungsmesser). Bei Biegeversuchen: Die Spannung der äusseren Faser bei der die erste bemerkbar bleibende Durchbiegung eintritt, bestimmt mit dem Durchbiegungsmesser.

Versuche zur Bestimmung der Elastizitäts-Grenze werden selten ausgeführt, da solche Versuche wiederholte Belastung und Entlastung erforderlich machen und beträchtliche Zeit beanspruchen. Für praktische Zwecke kann die Elastizitäts-Grenze als gleichbedeutend mit der Proportionalitäts-Grenze angesehen werden.

3. Streck-Grenze.—Spannung, bei der ein deutliches Anwachsen der Formänderung der Probe eintritt, ohne dass die Belastung steigt, gewöhnlich bestimmt durch Absinken des Lastanzeigers oder an den Formänderungsmasstäben für Zug-, Druck- oder Biegeversuch.

4. Zug-, Druck- oder Scherfestigkeit (Höchstlast).—Grösste Spannung, der die Probe unterworfen ist, bei langsamer Steigerung der Belastung bis zum Bruch, dividiert durch den ursprünglichen Probenquerschnitt.

5. Biegespannung (oder Bruchmodul).—Grösste Spannung in der äusseren Faser einer bis zum Bruch geprüften Probe in der Annahme, dass die empirische Biegeformel für Spannungen oberhalb der Proportionalitäts-Grenze angewendet werden kann. Für Proben mit einfachem rechteckigen Querschnitt und zentrischer Belastung gilt

$$1{,}5 \times \text{Last} \times \text{Stützweite}/\text{Querschnitt} \times \text{Höhe}$$

6. Torsions-Festigkeit (oder Bruchmodul für Torsion).—Grösste Spannung in der äusseren Faser der Probe beim Bruch, unter der Annahme, dass die Torsionsformel auch für Spannungen oberhalb der Proportionalitätsgrenze gilt. Für eine zylindrische Probe ist diese Torsions-Festigkeit

$$S = 5{,}1 \times \text{Drehmoment}/\text{Durchmesser}^3$$

Bei sehr formänderungsfähigen Materialien kann diese Bruchspannung als gleichmässig über den ganzen Querschnitt verteilt angesehen werden, und die obige Formel geht über in die Formel:

$$S = 3{,}82 \times \text{Drehmoment}/\text{Durchmesser}^3$$

7. Bruchdehnung.—Die prozentuale Dehnung wird gefunden, indem man die Längenzunahme nach dem Bruch durch die ursprüngliche Messlänge dividiert und mit 100 multipliziert. Die Bruchdehnung hängt von der Messlänge ab. Die Bruchdehnung ist ein Masstab für die Formänderungsfähigkeit des Materials.

8. Querschnittsverminderung.—Die prozentuale Querschnittsverminderung wird gefunden als das Verhältnis des Unterschiedes zwischen ursprünglichem und Bruchquerschnitt zu dem ursprünglichem Querschnitt multipliziert mit 100. Die Querschnittsverminderung zeigt allgemein die Formänderungsfähigkeit des Materials an.

9. Poisson'sche Konstante.—Das Verhältnis der Querkontraktion eines Stabes bezogen auf die Einheit des Durchmessers zur Längsdehnung, bezogen auf die Einheit der Länge eines

DEFINIZIONI

1. Limite di proporzionalità.—È quel valore della forza applicata dopo il quale le deformazioni cessano di essere proporzionali alla forza stessa. Le deformazioni sono misurate da apposito apparato (estensometro per le prove di trazione, compressometro per le prove di compressione, e deflettometro o flessimetro per le prove alla flessione). I valori vengono desunti da grafici.

2. Limite elastico.—Nelle prove di trazione e compressione. È quel valore della forza al quale corrisponde l'inizio dell'allungamento o del raccorciamento permanente. La deformazione permanente è messa in evidenza da un istrumento di alta precisione, e determinata mediante una serie di letture all'estensometro o compressometro.

Nelle prove di flessione. Quel valore della forza che si ha nella fibra estrema quando si manifesta una deflessione permanente apprezzabile determinata con il flessimetro.

Le prove per determinare il limite di elasticità si eseguono raramente, perchè richiedono ripetute applicazioni ed annullamenti della forza applicata, e quindi molto tempo. Per scopi pratici, si può considerare il limite di elasticità come coincidente con il valore del limite di proporzionalità.

3. Punto di snervamento.—È quel valore della forza in corrispondenza del quale si ha un aumento marcato nella deformazione del provino senza che il carico aumenti. Esso viene determinato osservando il momento in cui l'apparato registratore della forza applicata al provino cade rapidamente, oppure a mezzo di misurazione sul provino calibrato alle prove di trazione, compressione e flessione.

4. Carico di rottura alla trazione, compressione e taglio.—È il valore massimo dello sforzo al quale il provino è soggetto alla rottura, quando lo sforzo viene accresciuto lentamente. Questo valore viene riferito all'area della sezione trasversale primitiva del provino.

5. Modulo di rottura.—Massimo sforzo che si verifica nelle fibre maggiormente sollecitate di un provino che venga provato a flessione fino a rottura. Esso è calcolato con l'applicazione empirica della formula di sollecitazione per flessione, anche quando lo sforzo supera il limite di proporzionalità per sollecitazione della flessione stessa. Per pezzi di forma rettangolare semplice con carico concentrato nel centro, è eguale a:

$$\frac{1{,}5 \times \text{carico} \times \text{distanza tra gli appoggi}}{\text{area} \times \text{spessore}}$$

6. Sforzo di torsione (oppure modulo di rottura alla torsione).—Massimo sforzo che si verifica nelle fibre più sollecitate di un provino provato fino alla rottura, calcolato applicando empiricamente (anche al di sopra del limite di proporzionalità per torsione) la formula che dà la sollecitazione per torsione. Per un provino a sezione rotonda, la formula è:

$$S = \frac{5{,}1 \times \text{momento torcente}}{\text{diametro}^3}$$

Nei materiali duttili lo sforzo di rottura può essere considerato uniformemente distribuito sull'area della sezione trasversale, e la formula (2) diventa:

$$S = \frac{3{,}82 \times \text{momento torcente}}{\text{diametro}^3}$$

7. Allungamento.—L'allungamento percentuale è calcolato dividendo l'aumento di lunghezza dopo rottura per la lunghezza originale calibrata. L'allungamento percentuale dipende dalla lunghezza calibrata, cioè dalla lunghezza alla quale è riferito l'allungamento stesso. Questo allungamento indica la duttilità dei materiali.

10. Modulus of Elasticity ((*a*) in Tension or (*b*) in Compression).—Ratio of stress within the proportional limit to the corresponding strain as determined with a precise extensometer. Accurate determinations of the modulus of elasticity are made with a gage length at least 8 in. (203.2 mm) in length.

11. Modulus of Elasticity in Shear.—Ratio of stress within the proportional limit to the corresponding angular strain (in radians). The following theoretical relation exists between the modulus of elasticity in shear and the modulus of elasticity:

$$G = \frac{E}{2(1 + \lambda)}$$

where G is the modulus of elasticity in shear, E modulus of elasticity, and λ Poisson's ratio.

It is difficult to make a direct experimental determination of G on account of the presence of other stresses. It is usually determined by the torsion of a round bar.

12. Brinell Hardness Number.—Ratio of load, on a sphere used to indent the material to be tested, to the area of the spherical indentation produced. The standard sphere used is a 10 mm diameter hardened steel ball. The loads are (*a*) 3000 kg (6615 lb.) and (*b*) 500 kg (1102 lb.), and the time of application of load is 30 sec. Values shown in the tables are based on spherical areas computed from measurements of the diameters of the spherical indentations, by the following formula:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

P being load in kg, h being depth of indentation, D being diameter of ball and d being diameter of indentation, all lengths being expressed in millimeters. Brinell hardness values have a certain relation to tensile strength, and hardness determinations may be used to determine tensile strengths approximately by employing the proper conversion factor for the material under consideration.

13. Shore Scleroscope Hardness.—Height of rebound of a diamond-pointed hammer falling on the object from a fixed, stated height through a tube under the acceleration due to its own weight. On very soft materials a "magnifier" hammer is used in place of the commonly used "universal" hammer, and values may be converted to the corresponding "universal" value by multiplying the reading by $\frac{3}{4}$.

14. Erichsen Value.—The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical-pointed tool. The depth of impression (or cup), in millimeters, required to obtain fracture is the Erichsen value.

15. Bend Test.—(*a*) Angle through which the material can be bent without fracture; or (*b*) the number of bendings around a predetermined diameter; or (*c*) a minimum diameter around which the test piece can be bent through a stated angle.

16. Impact Resistance.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indicates the shock-resisting qualities of material. Is of particular value in ascertaining the influence of heat treatment. Impact value depends on the form of the specimen and type of apparatus, both of which must be stated.

(par unité de longueur) d'une barre soumise à une tension inférieure à la limite d'élasticité de la matière.

10. Module d'élasticité (*a*) **de traction,** (*b*) **de compression.**—C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) à la dilatation correspondante, cette détermination étant faite au moyen d'un extensomètre de précision. Les déterminations précises du module d'élasticité se font sur une longueur entre repères d'au moins 203,2 mm.

11. Module d'élasticité de glissement.—C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) au glissement correspondant (en radians). Il existe entre le module d'élasticité de glissement et le module d'élasticité la relation théorique suivante:

$$G = \frac{E}{2(1 + \lambda)}$$

ou G est le module d'élasticité de glissement, E le module d'élasticité et λ le coefficient de Poisson.

Il est difficile de faire une détermination expérimentale directe de G par le fait de la présence d'autres tensions. G est ordinairement déterminé par la torsion d'une barre de section circulaire.

12. Nombre de dureté Brinell.—C'est le rapport de la charge appliquée sur une bille qui pénètre dans la matière à essayer, à la surface de l'empreinte sphérique produite. La bille type utilisée est une sphère en acier trempé de 10 mm de diamètre. Les charges sont de (*a*) 3000 kg et (*b*) 500 kg et la durée d'application de la charge est de 30 secondes. Les valeurs données dans les tables sont basées sur les surfaces des calottes sphériques calculées d'après les diamètres mesurés des empreintes sphériques produites, par la formule suivante:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

P est la charge en kg, h la profondeur de l'empreinte, D le diamètre de la bille et d le diamètre de l'empreinte, toutes les longueurs étant exprimées en millimètres.

Il y a une certaine relation entre les nombres de dureté Brinell et la résistance de rupture, et des déterminations de dureté peuvent être employées pour déterminer approximativement la résistance de rupture en employant le facteur de conversion relatif à la matière considérée.

13. Dureté au scléroscope de Shore.—C'est la hauteur de rebondissement d'un petit marteau à pointe de diamant tombant sous l'effet de son propre poids sur l'object d'une hauteur fixe définie, en se déplaçant dans un tube. Lorsqu'il s'agit de matières très tendres, on utilise un marteau amplificateur à la place du marteau "universel" généralement employé, et les valeurs peuvent être converties en valeurs "universelles" correspondantes en multipliant la lecture par $\frac{3}{4}$.

14. Nombre d'Erichsen.—On effectue l'essai en supportant la tôle sur une bague circulaire et en la déformant au centre de la bague par un outil à pointe sphérique. Le nombre d'Erichsen est la profondeur de l'empreinte exprimée en millimètres, nécessaire pour produire la rupture.

15. Essai de pliage.—(*a*) C'est l'angle sous lequel la matière peut être pliée sans rupture; ou (*b*) le nombre de pliages successifs autour d'une barre de diamètre prédeterminé; ou (*c*) le diamètre minimum du cylindre autour duquel l'éprouvette peut être pliée sous un angle défini.

16. Résistance au choc.—(Bibliographie concernant l'essai de choc, Whittemore, *Proc. A. S. T. M.*, 1922.) Elle donne une mesure des qualités de résistance de la matière au choc. Elle est d'une importance particulière pour se rendre compte de l'influence d'un traitement thermique. Les valeurs obtenues aux essais de choc dépendent de la forme de l'éprouvette et du type d'appareil employé; ces deux éléments doivent être définis.

Stabes bei bestimmten Zugspannungen innerhalb der Elastizitätsgrenze des betreffenden Materials.

10. Elastizitäts-Modul (*a*) **für Zug oder** (*b*) **für Druck.**—Das Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zur entsprechenden Formänderung, ermittelt durch einen präzisen Dehnungsmesser. Genaue Bestimmungen Elastizitätsmoduls werden ausgeführt mit einer Mindestmesslänge von 203,2 mm.

11. Elastizitäts-Modul bei Scherbeanspruchung.—Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zu der entsprechenden Winkeländerung (in radians). Die folgende theoretische Beziehung besteht zwischen dem Elastizitätsmodul bei Scherbeanspruchung und den Elastizitätsmodul bei Zugbeanspruchung $G = E/2\ (1 + \lambda)$, worin G der Elastizitätsmodul für Scherbeanspruchung, E der Elastizitätsmodul für Zugbeanspruchung und λ die Poisson'sche Konstante ist. Es ist schwer, den Gleitmodul G direkt experimentell zu bestimmen wegen des Vorhandenseins von Nebenspannungen. Gewöhnlich wird er bestimmt durch einen Drehversuch mit einem Rundstab.

12. Brinell Härtezahl.—Das Verhältnis der Last, mit der eine Kugel in das zu prüfende Material eingedrückt wird, zur Fläche des erzeugten Kugeleindruckes. Die gebräuchliche Normalkugel ist eine gehärtete Stahlkugel von 10 mm Durchmesser. Die Kugelbelastungen sind (*a*) 3000 kg (6615 engl. Pfund) und (*b*) 500 kg (1102 engl. Pfund). Die Zeitdauer der Belastung beträgt 30 Sekunden. Die in den Tabellen angegebenen Werte für die Härtezahl werden aus Messungen der Durchmesser der erzeugten Kugeleindrücke unter Verwendung folgender Formel gewonnen:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\dfrac{D}{2} - \sqrt{\dfrac{D^2}{4} - \dfrac{d^2}{4}}\right)}$$

Darin bedeuten P die Kugelbelastung in kg, h die Eindrucktiefe in mm, D den Kugeldurchmesser in mm und d den Durchmesser des Eindrucks in mm. Die Brinell-Härtezahlen haben eine gewisse Beziehung zur Zugfestigkeit, Härtebestimmungen können deshalb angewandt werden, um angenähert die Zerreissfestigkeiten zu bestimmen, unter Anwendung eigenen Koeffizienten eines für jedes Material.

13. Shore Skleroskope-Härte.—Die Höhe des Rückpralls eines mit Diamantspitze versehenen Fallhammers, der aus einer bestimmten festgelegten Höhe durch eine Röhre unter Beschleunigung durch sein Eigengewicht auf die Probe fällt. Bei sehr weichen Materialien wird ein Spezialhammer angewandt an Stelle des gewöhnlich benutzten "Universalhammers;" die mit diesem Spezialhammer erzielten Werte können auf den Universalhammer bezogen werden durch Multiplikation der Ablesungen mit $3/4$.

14. Erichsen-Wert.—Der Versuch wird ausgeführt, indem ein Blech am Rande kreisförmig eingespannt und in der Mitte durch einen kugelförmigen Stempel eingedrückt wird. Die Tiefe des Eindrucks (oder der Beule) in mm, die erforderlich ist um Bruch hervorzurufen, ist der Erichsen-Wert.

15. Biegeprobe.—(*a*) Winkel, um den das Material gebogen werden kann ohne zu brechen; oder (*b*) die Zahl der Biegungen um einen bestimmten Durchmesser: oder (*c*) der kleinste Durchmesser, um den die Probe um einen bestimmten Winkel gebogen werden kann.

16. Schlag- oder Stossfestigkeit.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Gibt die Eigenschaften eines Materials an, Stossbeanspruchungen zu widerstehen und ist von besonderem Wert zur Feststellung des Einflusses von Wärmebehandlung. Der gefundene Schlagfestigkeitswert hängt von der Form der Probe und der Art des Apparates ab, beides muss also festgelegt werden.

17. Widerstand gegen Ermüdung.—Widerstand eines Materials gegen wiederholte, zwischen zwei bestimmten Spannungsgrenzen

8. Riduzione di area.—Percentuale di riduzione di area calcolata come rapporto della differenza tra l'area del provino prima e dopo la rottura (nel punto dove è avvenuta la rottura) e l'area originale. La riduzione di area indica generalmente la duttilità dei materiali.

9. Rapporto di Poisson.—Il rapporto della contrazione laterale per unità di diametro e l'allungamento longitudinale, riferito alla unità di allungamento di una barra sottoposta, nei suoi estremi, a sollecitazioni di tensione entro i limiti di elasticità del materiale.

10. Modulo di elasticità (*a*) **alla trazione,** (*b*) **alla compressione.**—Il rapporto del valore dello sforzo entro i limiti di proporzionalità e le corrispondenti deformazioni determinate con un estensometro molto preciso. Determinazioni accurate del modulo di elasticità sono fatte sopra una lunghezza calibrata del provino di almeno mm 203,2.

11. Modulo di elasticità al taglio.—Rapporto del valore dello sforzo entro i limiti proporzionali corrispondenti alle deformazioni angolari espresse in radianti. La relazione teorica che esiste tra il modulo di elasticità al taglio e il modulo di elasticità è:

$$G = \frac{E}{2(1 + \lambda)}$$

dove G è il modulo di elasticità al taglio, E quello di allungamento e λ il rapporto di Poisson.

È molto difficile eseguire un esperimento per misurare direttamente il valore di G, a causa della presenza di altri sforzi. Generalmente viene determinato eseguendo una prova di torsione sopra una barra rotonda.

12. Numero di durezza Brinell.—Rapporto tra il carico applicato sopra una sfera che penetra nel materiale sottoposto alla prova e l'area della impronta prodotta.

La sfera tipo è del diametro di mm 10 ed è di acciaio temprato. I carichi applicati sono: (*a*) kg 3000: (*b*) kg 500. Il tempo di applicazione del carico è di 30 secondi.

I valori riportati nelle tabelle si riferiscono alla misura dell'area fatta in base al diametro dell'impronta sferica.

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\dfrac{D}{2} - \sqrt{\dfrac{D^2}{4} - \dfrac{d^2}{4}}\right)}$$

dove P è il carico in kg, h la profondità dell'impronta, D il diametro della sfera adoperata e d il diametro della impronta. La durezza Brinell ha una certa relazione col carico di trazione, e le determinazioni della durezza possono servire a determinare appunto i carichi di trazione, in via approssimativa, mediante un fattore di conversione caratteristico per il materiale in esame.

13. Durezza allo scleroscopio di Shore.—Altezza del rimbalzo di un martello munito di una punta di diamante che cade sull'oggetto da una altezza nota e determinata, percorrendo un tubo sotto l'accelerazione dovuta al proprio peso. Per materiali molto teneri si usa un martello "moltiplicatore" invece del martello comune chiamato "universale," ed i valori possono essere convertiti in corrispondenti valori del martello universale moltiplicando la lettura per $3/4$.

14. Valori di Erichsen.—La prova si fa appoggiando il foglio di lamiera contro un anello e deformandolo nel centro a mezzo di un utensile pure sferico. La profondità dell'impressione in mm, che si ha per ottenere la frattura, è il valore di Erichsen.

15. Prove di piegamento.—(*a*) Angolo di cui il materiale può essere piegato senza fratturarsi, oppure: (*b*) numero di piegature attorno ad un predeterminato diametro, oppure: (*c*) diametro minimo attorno al quale il provino può essere piegato percorrendo un determinato angolo.

16. Resistenza all'urto.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indica la resistenza del materiale all'urto, ed ha particolare valore per accertare l'influenza dei trattamenti termici. Il valore all'urto dipende dalla forma del provino e dal tipo della macchina, ed entrambi questi elementi devono essere specificati.

17. Fatigue Resistance.—Resistance of material to a load varying continuously and cyclically between two fixed stress values.

Numerical values of Fatigue Resistance for the case of zero mean stress (Reversed Stresses) may be given as follows:

17a. Fatigue Strength.—The numerical values of upper and lower limits of stress cycle which cause failure after a definite number of repetitions.

17b. Endurance Limit.—The value of the upper (or lower) limit of stress cycle which is just insufficient to cause failure after a stated number of repetitions have been endured.

17c. True Endurance Limit.—The limiting value of the endurance limit, *i.e.*, the upper limit of a cycle of stress which can be applied an indefinitely great number of times without causing failure. The true endurance limit can never, of course, be determined experimentally. For many materials, however, it is found that if values of fatigue strength are plotted against the number of cycles N to fracture (logarithmically or semi-logarithmically) the resulting curve tends to become parallel to the N axis, affording strong evidence of the existence of a "true endurance limit."

Numerical values of fatigue resistance for cycles of stress whose mean stress is *not* zero may be given by stating the upper and lower limits of the stress cycles corresponding to 17*a* above, or by stating the value of the mean stress and the range (or semi-range) of the cycle. Consequently, corresponding to the above we shall have:

17d. Fatigue Strength Range.

17e. Endurance Range.

17f. True Endurance Range.

18. Ductility.—The *ductility* is the elongation of the test specimen measured after rupture on a distance distributed symmetrically on both sides of the place of rupture, and should be specified in % of the original length of the distance.

19. Acetyl Value.—Defined as g KOH (56.1) to neutralize the acetic acid from 1000 g acetylated oil ([1, 2, 7]). It gives hydroxy-acids + alcohols + oxidized fatty acids + unknown acids + mono- and di-glycerides + rancidity ([7]).

20. Iodine Value.—Per cent I_2 or its equivalent of other halogen absorbed ([3, 6, 12, 13]). Heat of bromination is proportional to I-value for most non-oxidized oils and fats ([4, 8]).

21. Saponification Value.—Mg KOH for complete saponification of 1 g of the oil, fat or wax. The corresponding mean equivalent weight of the substance is the "saponification equivalent." ([5]) gives a method for cold saponification.

22. Hehner Value.—Per cent insoluble fatty acids + unsaponifiables.

23. Polenske Value.—Proportion of insoluble volatile fatty acids (in terms of cm^3 of $0.1N$ KOH per 5 g of fat) obtained by Polenske's method of distillation ([10]).

24. Acid Value.—Mg KOH required to neutralize the free fatty acids in 1 g of oil or fat. The free fatty acids are also often expressed as a percentage of the principal fatty acid in the fat. Except in the case of the waxes, this value is not a constant, but varies with the degree of hydrolysis of the fat.

25. Reichert-Meissl Value.—Soluble volatile fatty acids in terms of $0.1N$ KOH per 5 g fat, under Meissl's test conditions ([9, 11, 14]).

LITERATURE

(For a key to the periodicals see end of volume)

([1]) Benedikt and Ulzer, *57*, **8**: 41; 87. ([2]) Grün, *Oel-Fett Industrie*, **1**: 339, 364; 19. ([3]) Hanus, *279*, **4**: 913; 01. ([4]) Hehner and Mitchell, *173*, **20**: 146; 95. ([5]) Henriques, *92*, **8**: 721; 95. **9**: 221; 96. ([6]) Hübl, *112*, **253**: 281; 84. ([7]) Lewkowitch, *173*, **24**: 319; 99. ([8]) Marden, *45*, **8**: 121; 16. ([9]) Meissl, *112*, **233**: 229; 79.

([10]) Polenske, *279*, **7**: 273; 04. ([11]) Reichert, *91*, **18**: 68; 79. ([12]) Waller, *136*, **19**: 1831; 95. ([13]) Wijs, *25*, **31**: 750; 98. ([14]) Wollner, *173*, **12**: 203; 87. *352*, **16**: 609; 87.

17. Résistance à la fatigue.—Résistance des matériaux soumis à une sollicitation variant d'une façon continue et périodique entre deux valeurs fixes.

Les valeurs numériques de la résistance à la fatigue pour le cas d'un effort moyen nul (efforts alternatifs) peuvent être données comme suit:

17a. Résistance à la fatigue.—Ce sont les valeurs numériques des limites supérieures et inférieures du cycle de tension qui produisent la rupture après un nombre défini de répétitions de l'effort.

17b. Limite d'endurance.—C'est la valeur de la limite supérieure (ou inférieure) du cycle de tension qui est juste insuffisante pour produire la rupture après un nombre défini de répétitions de l'effort.

17c. Limite d'endurance vraie.—C'est la valeur limite de la limite d'endurance, c'est-à-dire la limite supérieure d'un cycle de tension, qui peut être appliqué un nombre indéfini de fois sans produire la rupture. La limite d'endurance vraie ne peut naturellement jamais être déterminée expérimentalement.

Cependant, pour plusieurs matériaux, on a constaté que si l'on représente graphiquement les valeurs de la résistance à la fatigue en fonction du nombre de cycles N jusqu'à rupture (logarithmiquement ou semi-logarithmiquement), la courbe qui en résulte tend à devenir parallèle à l'axe des N, mettant ainsi bien en évidence l'existence d'une "limite d'endurance vraie."

Les valeurs numériques de la résistance à la fatigue pour des cycles de tension dont la valeur moyenne *n'est pas* zéro, peuvent être obtenues en fixant la limite supérieure et la limite inférieure des cycles de tension correspondant à 17*a* ci-dessus, ou en fixant la valeur de la tension moyenne et l'amplitude (ou demi amplitude) du cycle. Par conséquent, correspondant à ce que nous avons ci-dessus, nous aurons:

17d. Amplitude de la résistance à la fatigue.

17e. Amplitude d'endurance.

17f. Amplitude d'endurance vraie.

18. Ductilité.—*La ductilité* est l'allongement d'une éprouvette essayée, mesuré après rupture sur une distance répartie symétriquement de part et d'autre de la section de rupture. Elle doit être exprimée en % de la longueur initiale entre repères.

19. Indice d'acétyle.—Il est défini par le nombre de g de KOH (56,1) nécessaires pour neutraliser l'acide acétique de 1000 g d'huile acétylée ([1, 2, 7]). Il donne les hydroxyacides + alcools + les acides gras oxydés + acides inconnus + mono et diglycérides + rancidité.

20. Indice d'iode.—Pourcentage de I_2 ou son équivalent d'un autre halogène absorbé ([3, 6, 12, 13]). La chaleur de bromuration est proportionnelle á l'indice d'iode pour la plupart des huiles et graisses non oxydées ([4, 8]).

21. Indice de saponification.—Mg KOH pour la saponification complète de 1 g d'huile, graisse ou cire. Le poids équivalent moyen correspondant à la substance est "l'équivalent de saponification." ([5]) donne une méthode pour la saponification à froid.

22. Indice de Hehner.—Pourcent d'acides gras insolubles + insaponifiables.

23. Indice de Polenske.—Proportion d'acides gras volatils insolubles (exprimés en cm^3 de $0{,}1N$ KOH pour 5 g de graisse) obtenue par la méthode de distillation de Polenske ([10]).

24. Indice d'acide.—Mg KOH nécessaires pour neutraliser les acides libres contenus dans 1 g d'huile ou de graisse. On exprime aussi souvent les acides gras libres en pourcent des acides gras principaux contenus dans la graisse. Excepté dans le cas des cires, cette valeur n'est pas une constante, mais elle varie avec le degré d'hydrolyse de la graisse.

25. Indice de Reichert-Meissl.—Acides gras volatils, solubles exprimés en $0.1N$ KOH pour 5 g de graisse, suivant les conditions de l'essai de Meissl ([9, 11, 14]).

schwingenden Beanspruchungen. Zahlenmässige Werte für den Ermüdungswiderstand können für den Fall, dass der Spannungsmittelwert Null ist (vollkommene Umkehrung der Spannung nach Richtung und Grösse) folgendermassen ausgedrückt werden:

17a. Ermüdungsfestigkeit.—Die zahlenmässigen Werte der oberen und unteren Grenzen des Spannungswechsels, welche nach einer bestimmten Anzahl von Wiederholungen Bruch hervorrufen.

17b. Dauerbruchgrenze.—Der Wert der oberen (od. unteren) Grenze des Spannungswechsels, welcher gerade noch nicht ausreicht, um den Bruch nach einer bestimmten Zahl von der Probe erlittener Lastwechsel hervorzurufen.

17c. Wahre Dauerbruchgrenze.—Der Grenzwert der Ermüdungsgrenze, d.h., die obere Grenze eines Spannungswechsels, welcher unbegrenzt häufig—ohne Bruch zu verursachen—angewandt werden kann. Die wahre Dauerbruchgrenze kann selbstverständlich niemals experimentell bestimmt werden. Sie ist jedoch für viele Materialien festgestellt, sobald man die Werte der Ermüdungsfestigkeit in Abhängigkeit von der Zahl der Spannungswechsel N, die zum Bruch führen, logarithmisch (oder für die eine Achse logarithmisch) aufgetragen, darstellt, die sich ergebende Kurve parallel zur N-Achse zu verlaufen strebt und damit einen sicheren Anhalt für das Vorhandensein einer "wahren Dauerbruchgrenze" bietet. Zahlenmässige Werte des Widerstandes gegen Ermüdung für Lastwechselfolgen, deren Spannungsmittelwerte nicht Null sind, können wiedergegeben werden durch Angabe der oberen und unteren Grenzen des Spannungswechsels, entsprechend 17*a* oder durch Angabe des Spannungsmittelwertes und der ganzen (oder halben) Amplitude. Entsprechend obigem, kann man demnach setzen:

17d. Ermüdungsfestigkeit für bestimmte Spannungswechsel.

17e. Dauerbruchfestigkeit für bestimmte Spannungswechsel.

17f. Wahre Dauerbruchfestigkeit für bestimmte Spannungswechsel.

18. Formänderungsfähigkeit.—Die Formänderungsfähigkeit ist die Verlängerung des Probestabes, gemessen nach dem Bruch auf eine Länge, die symmetrisch zu beiden Seiten der Bruchstelle verteilt ist. Sie ist in Prozenten der ursprünglichen Messlänge anzugeben.

19. Acetyl-Zahl.—Gibt die Gramme KOH (56,1) an, die für die Neutralisation der Essigsäure in 1000 g des acetylierten Öles notwendig sind ([1, 2, 7]). Damit sind bestimmt: Oxysäuren + Alkohole + oxydierte Fettsäuren + unbekannte Säuren + Mono und Diglyceride + Ranzigkeit ([7]).

20. Jod-Zahl.—Ist durch Prozente Jod bestimmt(Äquivalent den anderen absorbierbaren Halogenen) ([3, 6, 12, 13]). Die Bromierungs-Wärme ist proportional der Jod-Zahl bei den meisten nicht oxydierten Fetten ([4, 8]).

21. Verseifungs-Zahl.—Gibt die mg KOH an die für die vollständige Verseifung von 1 g Fett, Öl, Wachs notwendig sind. Das entsprechende mittlere Äquivalent-Gewicht der Substanz ist das "Verseifungs-Äquivalent." ([5]) gibt eine Methode für die Verseifung in der Kälte.

22. Hehner'sche-Zahl.—Ist Prozente unlösliche Fettsäuren + Unverseifbares.

23. Polenske-Zahl.—Gibt die Anzahl cm³ 0.1N KOH an die nötig sind, um die flüchtigen unlöslichen Fettsäuren für 5 g Fett zu neutralisieren, die entsprechend der Destillationsmethode nach Polenske ([10]) erhalten werden.

24. Säure-Zahl.—Ist die Anzahl mg KOH die für die Neutralisation der freien Fettsäuren von 1 g Öl oder Fett notwendig sind. Die freien Fettsäuren werden öfters in Prozenten der Hauptfettsäure im Fett angegeben. Mit Ausnahme bei den Wachsarten ist diese Zahl nicht konstant und ändert sich mit dem Grade der Hydrolyse des Fettes.

25. Reichert-Meissl'sche-Zahl.—Lösliche flüchtige Fettsäuren ausgedrückt in cm³ 0.1N KOH für 5 g Fett, bestimmt nach dem Vorgange von Meissl ([9, 11, 14]).

17. Resistenza alla fatica.—Resistenza del materiale sottoposto a sforzi varianti in modo continuo e ciclico tra due valori fissi.

Valori numerici della resistenza alla fatica nel caso di uno sforzo medio eguale a zero (sforzi invertiti) possono essere indicati nella maniera seguente:

17a. Resistenza alla fatica.—I valori numerici dei limiti superiore ed inferiore delle sollecitazioni cicliche che producono rottura dopo un numero definito dei ripetizioni.

17b. Limite di durata.—Valore superiore (o inferiore) della massima sollecitazione ciclica insufficiente a produrre la rottura dopo essere stata applicata un determinato numero di volte.

17c. Limite vero (o pratico) di durata.—Valore limite del limite di durata, cioè valore superiore della massima sollecitazione ciclica che può essere applicata un gran numero di volte senza produrre rottura. Naturalmente, il vero limite di durata non può mai essere determinato sperimentalmente. Tuttavia, per molti materiali si è trovato che, se si riportano in un diagramma i valori della sollecitazione in funzione del numero di cicli N che producono la frattura (logaritmicamente o semilogaritmicamente) la curva risultante tende a divenire parallela all'asse N mostrando all' evidenza che esiste un "vero limite di durata."

Valori numerici di resistenza alla fatica per sollecitazioni cicliche nelle quali i valori medi delle sollecitazioni sono diversi a zero possono essere dati stabilendo i limiti superiore ed inferiore dei cicli delle sollecitazioni corrispondenti a 17*a*, oppure stabilendo il valore della sollecitazione media e l'intervallo (o semintervallo) del ciclo. Di conseguenza, d'accordo con quanto sopra si avrà:

17d. Ampiezza delle oscillazioni tra i valori delle sollecitazioni cicliche alla fatica.

17e. Ampiezza od oscillazioni di durata.

17f. Ampiezza od oscillazioni pratiche di durata.

18. Duttilità.—La duttilità è l'allungamento del provino, e viene misurata dopo la rottura sopra una lunghezza distribuita simmetricamente da entrambe le parti del punto di rottura. Essa è specificata in percento della lunghezza originale primitiva.

19. Numero di acetile.—Indica i grammi di KOH (56,1) necessari per neutralizzare l'acido acetico in 1000 g di olio acetilato ([1, 2, 7]). Esso è in relazione: con gli ossiacidi + gli alcooli + gli acidi grassi ossidati + acidi sconosciuti + mono e digliceridi, + la rancidità ([7]).

20. Numero di iodio.—Percento di I_2 (o suo equivalente di altri alogeni) fissato ([3, 6, 12, 13]). Il calore di bromurazione è proporzionale al numero di iodio per la maggior parte degli olii e grassi non ossidati ([4, 8]).

21. Numero di saponificazione.—Mg di KOH necessari per la completa saponificazione di 1 g di olio, grasso o cera. Il corrispondente peso equivalente medio della sostanza è "l'equivalente di saponificazione." ([5]) dà un metodo di saponificazione a freddo.

22. Numero di Hehner.—Percento di acidi grassi isolubili + sostanze insaponificabili.

23. Numero di Polenske.—Quantità di acidi grassi volatili insolubili (riferito in cm³ di KOH 0.1N per 5 g di grasso) ottenuta col metodo di distillazione di Polenske ([10]).

24. Numero di acidità.—Mg di KOH richiesti per neutralizzare gli acidi grassi liberi di 1 g di olio o grasso. Gli acidi grassi liberi sono spesso riferiti come percentuale dell'acido principale contenuto nel grasso. All'infuori del caso delle cere questo numero non è una costante, ma varia col grado di idrolisi del grasso.

25. Numero di Reichert-Meissl.—Acidi grassi volatili solubili, espressi in cm³ di KOH 0.1N per 5 g di grasso, ottenuti nelle condizioni di procedimento Meissl ([9, 11, 14]).

COOPERATING EXPERTS—VOLUME TWO

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STRENGTH AND RELATED PROPERTIES OF WOODS

COLUMN HEADINGS	ENTÊTES DES COLONNES	KOPFTITEL	TITOLI DELLE COLONNE
Index number.	Nombre index.	Index Nummer.	Numeri indice.
Botanical name.	Nom botanique.	Botanischer Name.	Nome botanico.
Family; genus and species.	Famille; genres et espèces.	Familie; Genus und Art.	Famiglia; genere e specie.
Common name.	Nom commun.	Gebräuchlicher Name.	Nome comune.
Place of growth of material tested.	Lieu où a poussé le matériel soumis aux essais.	Ort an dem das untersuchte Material gewachsen ist.	Luogo di origine del materiale esaminato.
Seasoning condition.	Condition de séchage à l'air.	Trocknungsbedingungen.	Condizione di stagionatura.
Bulk density of wood substance; oven-dry weight divided by volume in condition stated.	Densité apparente du bois; poids du bois séché au four divisé par le volume dans la condition spécifiée.	Raumgewicht des Holzes; Gewicht nach der Ofentrocknung dividiert durch das Volumen im angegebenem Zustand.	Densità della sostanza legnosa: peso dopo seccata al forno diviso per il volume nella condizione stabilita.
Bulk density of piece; weight of sample divided by its volume in condition stated.	Densité apparente de la pièce; poids de l'éprouvette divisé par son volume dans la condition spécifiée.	Raumgewicht des Stückes: Gewicht der Probe dividiert durch das Volumen im angegebenem Zustand.	Densità del pezzo: peso del campione diviso per il suo volume nella condizione stabilita.
Oven-dry.	Séché au four.	Ofen trocken.	Seccato al forno.
Green.	Vert.	Frisch (grün).	Verde.
Air-dry.	Séché à l'air.	Luft trocken.	Seccato all'aria.
Moisture content.	Teneur en humidité.	Feuchtigkeitsgehalt.	Contenuto di umidità.
Shrinkage from green to oven-dry condition.	Retrait à partir du bois vert lorsque séché au four.	Schwinden vom frischen bis zum Ofen trockenem Zustand.	Contrazione dallo stato verde a quello di essiccamento nel forno.
Static and impact bending; compression parallel or perpendicular to grain.	Essai de flexion statique et au choc; compression parallèle et perpendiculaire à la fibre.	Statische und dynamische Biegefestigkeit; Druck parallel oder senkrecht zur Faser.	Incurvamento alla flessione statica e all'urto; compressione parallela o perpendicolare alla vena del legno.
Fiber stress at elastic limit.	Tension de la fibre à la limite élastique.	Faserspannung an der Elastizitätsgrenze.	Trazione della fibra al limite di elasticità.
Modulus of rupture.	Module de rupture.	Bruchfestigkeit.	Modulo di rottura.
Modulus of elasticity.	Module d'élasticité.	Elastizitätsmodulus.	Modulo di elasticità.
Work to elastic limit.	Travail jusqu'à la limite élastique.	Arbeit bis zur Elastizitätsgrenze.	Lavoro fino al limite di elasticità.
Work to maximum load.	Travail jusqu'à charge maximum.	Arbeit bis zur Höchstlast.	Lavoro fino al carico massimo.
Total work.	Travail total.	Gesamtarbeit.	Lavoro totale.
Height of drop causing complete failure.	Hauteur de chute occasionnant une rupture complète.	Fallhöhe die zum vollkommenem Bruch führt.	Altezza del peso causante completa rottura.
Maximum crushing strength.	Résistance maximum à l'écrasement.	Schlagfestigkeit.	Massima forza schiacciante.
Shear; tension perpendicular to grain; hardness; cleavage.	Cisaillement tension perpendiculaire à la fibre; dureté; clivage.	Scherung; Druck senkrecht zur Faser; Härte; Spaltbarkeit.	Taglio; tensione perpendicolare alla vena; durezza; fendimento.

I. NORTH AMER-

UNITED STATES FOREST

The following data on certain woods of North America are based on an extensive series of tests of small specimens free of defects. All the tests were conducted under a uniform procedure, so that the results are strictly comparable. Analysis of the test figures has made it possible to establish definite density-strength relations, which are represented by the equations given in the first section of the table (Table 1). These equations are all of the parabolic type, the degree being determined to the nearest quarter-unit. By substituting the appropriate specific gravity for a given species (columns 8 and 9) in the equation for any property, the value of the corresponding property may be obtained.

In most species, however, there is a very considerable departure of average test results from the general equation values, although very few species, thus far investigated, are either wholly above or wholly below normal, all properties considered. Since the deviation of a property from the normal value as determined by the equation often indicates the special fitness or unfitness of the species for a particular use, it becomes necessary to supplement the equations with departure factors, for the properties of each species. Such factors, expressed as *percentages* and listed in order below the respective equations, make up the second part of Table 1. By multiplying the value, F, computed by the equation, by the proper correction factor, the actual average value for the property and species in question may be determined.

Example: To find the modulus of rupture of air-dried shagbark hickory. The finding list shows this to be No. 62, *Hicoria ovata*. From the equation of column 15 we find $F = 18.1\ D_d^{1.25}$. For No. 62 we find (column 9) $D_d = 0.724$ and (column 15) correction factor = 119%, whence

$$F = 1.19 \times 18.1 \times (0.724)^{1.25} = 14.4 \text{ kg/mm}^2 = 14.4 \times 1422 = 20\ 500 \text{ lb./in.}^2$$

The test methods that were used conform to Tentative Standard D143-24T of the American Society for Testing Materials, as set forth in *Proc. A. S. T. M.* 939; 24. (General description in U. S. Dept. Agr., *Bull.* No. 556.) The principal data relating to the procedure for each kind of test are summarized as follows:

Shrinkage in Volume.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Volume determined when green (unseasoned) and after oven-drying to constant weight at 100°C. Specimens thoroughly air-seasoned prior to drying in oven.

Shrinkage, Radial and Tangential.—Specimen 2.54 × 10.16 × 2.54 cm (1 × 4 × 1 in.). Width measured when green (unseasoned) and after oven-drying to constant weight at 100°C. Specimens thoroughly air-seasoned prior to drying in oven.

Static Bending.—Specimen 5.08 × 5.08 × 76.20 cm (2 × 2 × 30 in.). Center loading, 71.12 cm (28 in.) span. Load applied by testing machine head moving 0.254 cm (0.10 in.) per min. Total work is defined as that obtained by continuing the test until either a 15.24 cm (6 in.) deflection is reached or the load falls to 90.7 kg (200 lb.) or less.

Impact Bending.—Specimen and span as above. 22.7 kg (50 lb.) hammer dropped first from 2.54 cm (1 in.) height, next from 5.08 cm (2 in.) height, etc., up to 25.4 cm (10 in.), then from height increments of 5.08 cm (2 in.) until failure.

Compression Parallel to Grain.—Specimen 5.08 × 5.08 × 20.32 cm (2 × 2 × 8 in.). End load, testing machine head moving 0.061 cm (0.024 in.) per min.

Les données indiquées ici, relatives à certains bois de l'Amérique du Nord, sont basées sur une série d'expériences faites sur de petites éprouvettes exemptes de défauts. Tous les essais ayant été effectués suivant une procédure uniforme, les résultats sont donc strictement comparables. L'analyse des chiffres obtenus aux essais a permis d'établir des relations définies entre la densité et la résistance, qui sont représentées par les équations inscrites dans la première section de la table (Table 1). Ces équations sont toutes du type parabolique, le degré étant déterminé au quart d'unité le plus proche. En substituant le poids spécifique approprié pour une espèce donnée (colonnes 8 et 9) dans l'équation relative à une propriété donnée, on peut obtenir la valeur correspondante de la propriété.

Cependant pour la plupart des espèces il y a un écart considérable entre les résultats moyens des essais et les valeurs déduites de l'équation générale; pour autant que les expériences effectuées l'ont démontré, il n'y a qu'un petit nombre d'espèces qui sont, ou en entier au-dessus ou en entier au-dessous de la normale pour toutes les propriétés considérées. Comme l'écart d'une propriété de la valeur normale, ainsi qu'elle est déterminée par l'équation, indique souvent la convenance spéciale de l'espèce pour un usage particulier, ou sa non-convenance, il est nécessaire de compléter les équations par des facteurs de correction pour les propriétés de chaque espèce. Ces facteurs, exprimés en pourcentage et inscrits dans l'ordre au-dessous des équations respectives, constituent la deuxième partie de la Table 1. En multipliant la valeur F calculée au moyen de l'équation par le facteur de correction convenable, on peut déterminer la valeur moyenne de la propriété de l'espèce en question.

Exemple: Soit à déterminer le module de rupture du "shagbark hickory" séché à l'air. La liste de recherches montre qu'il s'agit du No. 62 *Hicoria ovata*. De l'équation de la colonne 15 on trouve $F = 18{,}1\ D_d^{1{,}25}$. On trouve pour le No. 62 (colonne 9) $D_d = 0{,}724$ et (colonne 15) le facteur de correction = 119%, d'où

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1{,}25} = 14{,}4 \text{ kg/mm}^2 = 14{,}4 \times 1\ 422 = 20\ 500 \text{ lb./in.}^2$$

Les méthodes d'essais qui ont été utilisées sont conformes à l'examen type D143-24T de la société américaine pour l'essai des matériaux, ainsi qu'elles sont décrites dans *Proc. A. S. T. M.* 939: 24 (*cf.* U. S. Dept. Agr. *Bull.* 556). Les données principales relatives à la procédure pour chaque sorte d'essai sont rassemblées ci-dessous:

Retrait en volume.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Le volume est déterminé lorsque le bois est vert, puis, après séchage à poids constant au four à 100°C. Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

Retrait radial et tangentiel.—Eprouvette 2,54 × 10,16 × 2,54 cm (1 × 4 × 1 pouce). La largeur est mesurée sur le bois vert et après séchage à poids constant, au four à 100°C. Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

Essai de flexion statique.—Eprouvette 5,08 × 5,08 × 76,20 cm (2 × 2 × 30 pouces); charge centrale; portée 71,12 cm (28 pouces). La charge est appliquée par une machine à essai dont la pièce mobile se déplace de 0,254 cm (0,10 pouces) à la minute. Le travail total est défini par celui qu'on obtient en continuant l'essai jusqu'à ce qu'une flèche de 15,25 cm soit obtenue, ou que la charge tombe à 90,7 kg (200 lb.) ou moins.

ICAN WOODS

Products Laboratory

Die hier angegebenen Werte bestimmter nordamerikanischer Hölzer ergeben sich aus einer ausgedehnten Serie von Prüfungen an einer kleinen Zahl von fehlerfreien Arten. Alle Prüfungen sind bei einheitlichem Vorgange ausgeführt worden, so, dass sie direkt vergleichbar sind. Die Analysen der Zahlenwerte der Prüfungsergebnisse machten es möglich gewisse Beziehungen zwischen Dichte und Festigkeit aufzustellen, die durch Gleichungen im ersten Abschnitt der Tafel 1 wiedergegeben sind. Diese Gleichungen sind alle vom parabolischen Typus, der Exponent in der Gleichung ist auf die nächste Viertel-Einheit bestimmt. Durch Einsetzung des entsprechenden spezifischen Gewichtes für eine bestimmte Art (Reihe 8 und 9) in die Gleichung für ihrgend eine Eigenschaft, erhält man den Wert für die entsprechende Eigenschaft.

Bei vielen Arten jedoch ist eine bemerkenswerte Abweichung des durchschnittlichen Wertes des Prüfungsergebnisses von dem Werte, der sich aus der allgemeinen Gleichung ergibt, vorhanden. Es gibt indessen nur sehr wenige Arten, so weit untersucht, deren berücksichtigten Eigenschaften zur Gänze entweder über oder unter dem normalen Werten liegen. Da die Abweichung einer Eigenschaft, von dem durch die Gleichung erhaltenen Wert, häufig die besondere Eignung oder Nichteignung einer Art für eine besondere Verwendung anzeigt, wird es notwendig, für die Eigenschaft jeder einzelnen Art die Gleichung durch einen Abweichungsfaktor zu ergänzen. Solche Faktoren, in *Prozenten* ausgedrückt, befinden sich geordnet unter den entsprechenden Gleichungen und machen den zweiten Teil der Tafel 1 aus. Durch Multiplikation des Wertes F, der nach der Gleichung gefunden ist, mit dem eigenen Korrektionsfaktor, erhält man richtige Mittelwerte für die Eigenschaft des fraglichen Musters.

Beispiel: Es ist die Bruchfestigkeit von lufttrockenem Hykorynussbaum zu finden. Die Nachschlagsliste zeigt, dass dies No. 62 *Hicoria ovata* ist. Aus der Gleichung der Reihe 15 findet man $F = 18{,}1\ D_d^{1,25}$. Für No. 62 findet man (Reihe 9) $D_d = 0{,}724$ und (Reihe 15) den Korrektionsfaktor = 119%, mithin

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1,25} = 14{,}4 \text{ kg/mm}^2$$

Die angewandten Prüfungsmethoden entsprechen der Standard Prüfung D143-24T der American Society for Testing Materials, wie es in *Proc. A. S. T. M.* 939; 24 (*cf.* U. S. Dep. Agr. *Bull.* 556) mitgeteilt wird. Die hauptsächlichsten Angaben, die den Vorgang bei jeder besonderen Prüfung bezeichnen, sind zusammengestellt, die folgenden:

Volumabnahme (Schwindung).—Muster 5,08 × 5,08 × 15,24 cm. Das Volumen wurde in unausgetrocknetem Zustande und dann nach der Trocknung im Ofen bei 100°C, bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

Volumabnahme, tangential und radial.—Muster 2,54 × 10,16 × 2,54 cm. Die Masse sind im ungetrocknetem Zustande abgenommen und dann nach der Ofentrocknung bei 100°C, bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

Statischer Biegeversuch.—Muster 5,08 × 5,08 × 76,20 cm, Mittelbelastung, 71,12 cm Spannweite, Belastung durch eine Festigkeitsmaschine, derart, dass die Durchbiegung 0,254 cm in der Minute beträgt. Die gesammt Arbeit ist diejenige, die bei

I valori qui riportati per certi legni dell'America del Nord sono il risultato di una estesa serie di prove eseguite sopra un piccolo numero di specie senza difetti. Tutti i saggi sono stati condotti con lo stesso metodo, per modo che i risultati sono strettamente confrontabili. L'esame dei valori numerici ha permesso di stabilire alcune relazioni fra densitá e resistenza, le quali sono rappresentate dalle equazioni riprodotte nella prima parte della tabella (Tabella 1). Queste equazioni sono tutte di tipo parabolico, e il grado è determinato con l'approssimazione del quarto dell'unità.

Introducendo nell'equazione per una data proprietà il peso specifico di una determinata specie (colonne 8 e 9) si ottiene il valore della proprietà corrispondente.

In molte specie la media dei risultati dei saggi scarta notevolmente dai valori che si ottengono dall'equazione generale; solo in poche però, tutti i valori sono sempre al di sopra e sempre al di sotto dei normali.

Siccome lo scarto di una proprietà dal valore risultante dall' equazione sta spesso ad indicare se una specie è adatta o no ad uno speciale impiego, è necessario completare le equazioni con dei fattori di correzione per le proprietà di ogni specie. Questi fattori, espressi in percento, sono riportati sotto le equazioni corrispondenti e costituiscono la seconda parte della Tabella 1. Moltiplicando il valore F dato dall'equazione per il rispettivo fattore di correzione, si ottengono valori medi esatti per la proprietà del campione in questione.

Esempio: Si debba trovare la resistenza alla rottura dello "shagbark hickory" seccato all'aria. Dall'elenco di riferimento si ricava che si tratta del No. 62, *Hicoria ovata*. Dall'equazione della colonna 15 si ha $F = 18{,}1\ D_d^{1,25}$. Per il No. 62 si trova $D_d = 0{,}724$ (colonna 9) e come fattore di correzione 119% (colonna 15), per modo che si ha

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1,25} = 14{,}4 \text{ kg/mm}^2$$

I metodi di prova adoperati corrispondono alle norme D143-24T della American Society for Testing Materials, quali si trovano indicate nei *Proc. A. S. T. M.* 939; 24 (*v.* U. S. Dep. Agr. *Bull.* 556). Le indicazioni principali riferentisi a ogni specie di saggio sono le seguenti:

Contrazione di volume.—Dimensioni della provetta 5,08 × 5,08 × 15,24 cm. Il volume viene determinato su legno non stagionato e su legno seccato in forno a 100°C fino a costanza di peso. I provini vengono seccati completamente all'aria prima che nel forno.

Diminuzione di volume, tangenziale e radiale.—Dimensioni della provetta 2,54 × 10,16 × 2,54 cm. La larghezza viene misurata su legno non stagionato e su legno seccato in forno a 100°C fino a costanza di peso. Le provette vengono seccate completamente all'aria prima che nel forno.

Flessione statica.—Dimensioni della provetta 5,08 × 5,08 × 76,20 cm. Carico centrale, distanza tra gli appoggi 71,12 cm. Il carico viene applicato con una macchina di prova in modo che la freccia di incurvamento cresca con la velocità di 0,254 cm al minuto. Il lavoro totale è quello che si ottiene prolungando il saggio finchè o si raggiunge una freccia di 15,24 cm o il carico si abbassa a 90,7 kg o meno.

Compression Perpendicular to Grain.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Load applied to side through a steel plate 5.08 cm (2 in.) wide laid across center of piece and at right angles to its length, ⅓ of surface being thus directly subjected to compression; testing machine head moving 0.061 cm (0.024 in.) per min.

Shear Parallel to Grain.—Specimen 5.08 × 5.08 × 6.35 cm (2 × 2 × 2.5 in.). Undercut at one end to permit shear over area 5.08 × 5.08 cm (2 × 2 in.); testing machine head moving 0.038 cm (0.015 in.) per min.

Tension Perpendicular to Grain.—Specimen as above. Transverse recess bored at each end to permit gripping for tension over 5.08 × 2.54 cm (2 × 1 in.) area; testing machine head moving 0.635 cm (0.25 in.) per min.

Hardness.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Load required to embed a steel ball having a maximum cross-sectional area of 1 cm^2 to ½ its diam.; testing machine head moving 0.635 cm (0.25 in.) per minute.

Cleavage Parallel to Grain.—Specimen 5.08 × 5.08 × 9.525 cm (2 × 2 × 3¾ in.). Transverse recess bored at one end to permit gripping for cleavage of specimen over 5.08 cm (2 in.) width and along a 7.62 cm (3 in.) length; testing machine head moving 0.635 cm (0.25 in.) per min.

Conversion Factors

Multiply	By	To obtain
Kg per mm^2	1422	lb. per $in.^2$
Kg-mm per mm^3	1422	in.-lb. per $in.^3$
Meters	39.37	in.
Kg	2.205	lb.
Kg per mm of width	56	lb. per in. of width

Essai de flexion par choc.—Eprouvette et portée comme ci-dessus. Un marteau de 22,7 kg (50 lb.) tombe premièrement d'une hauteur de 2,54 cm (1 pouce), ensuite de 5,08 cm (2 pouces) de haut, etc., jusqu'à 25,4 cm (10 pouces), ensuite par augmentations successives de hauteur de 5,08 cm (2 pouces) jusqu'à rupture.

Compression parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 20,32 cm (2 × 2 × 8 pouces). Charge finale, machine à essai dont la pièce mobile se déplace de 0,061 cm par minute.

Compression perpendiculaire à la fibre.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Charge appliquée sur le côté par l'intermédiaire d'une plaque d'acier de 5,08 cm de largeur disposée au milieu de la pièce et normalement à sa longueur, de façon que ⅓ de la surface soit soumis à la compression; machine à essai dont la pièce mobile se déplace de 0,061 cm (0,024 pouce) par minute.

Cisaillement parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 6,35 cm (2 × 2 × 2½ pouce). Ecrénée à une extrémité pour permettre le cisaillement sur une surface de 5,08 × 5,08 cm (2 × 2 pouces); machine à essai dont la pièce mobile se déplace de 0,038 cm (0,015 pouce) par minute.

Traction perpendiculaire à la fibre.—Eprouvette comme ci-dessus. Niche transversale découpée à chaque extrémité de façon à permettre la traction sur une surface de 5,08 × 2,54 cm (2 × 1 pouce). Machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

Dureté.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Charge nécessaire pour enfoncer une bille d'acier ayant une section maximum de 1 cm^2, de la moitié de son diamètre. Machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

Clivage parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 9,525 cm (2 × 2 × 3¾ pouces). Niche transversale découpée à une extrémité de façon à permettre le clivage de l'éprouvette sur une largeur de 5,08 cm (2 pouces) et le long de 7,62 cm (3 pouces); machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

WOODS OF THE PHILIPPINE ISLANDS

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Introduction

Density and strength values for five woods of commerce have been determined. The testing methods used and manner of displaying the results are identical with those used by the U. S. Forest Products Laboratory and the results have therefore been incorporated at the end of Table 1 below.

CANADIAN WOODS

A number of the species listed in Table 1 below have also been tested by the Canadian Forest Products Laboratory, using samples obtained from trees grown in Canada. As far as can be definitely determined, these woods are substantially the same in properties as like species grown in the United States.

BOIS DES ILES PHILIPPINES

Bureau de Sylviculture et Bureau de Science des Iles Philippines

Introduction

Les valeurs de densité et de résistance ont été déterminées pour cinq bois du commerce. Les méthodes d'essais utilisées, et la façon de disposer les résultats sont identiques à celles utilisées par le U. S. Forest Products Laboratory (voir ci-dessus); c'est pourquoi les résultats ont été incorporés à la fin de la Table 1.

BOIS CANADIENS

Un certain nombre d'espèces mentionnées au bas de la Table 1 ont aussi été essayées par le "Laboratoire des Produits Forestiers Canadiens" qui employa des échantillons provenant d'arbres ayant poussé au Canada. Pour autant qu'on peut le déterminer d'une façon définie, ces bois sont les mêmes, au point de vue de leurs propriétés, que ceux des mêmes espèces croissant aux États-Unis.

fortgesetzter Prüfung entweder eine 15,24 cm Durchbiegung erreicht, oder das Gewicht fällt auf 90,7 kg oder weniger.

Schlagbiegeversuch.—Muster und Grösse wie oben. Ein 22,7 kg Hammer fällt zuerst von 2,54 cm dann von 5,08 cm u. s. w. Höhe herunter, bis 25,4 cm, von hier an, in Höhenzunahmen um 5,08 cm bis zum Bruch.

Druckversuch parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 20,32 cm. Endlast, Festigkeitsmaschine derart, dass Zusammendrückung in der Minute 0,061 cm beträgt.

Druck senkrecht zur Faserrichtung.—Muster 5,08 × 5,08 × 15,24 cm. Das Gewicht an die Seite drückt auf eine Stahlplatte von 5,08 cm Weite, die um die Mitte des Stückes in rechten Winkeln zu seiner Länge angelegt ist, wodurch ⅓ der Oberfläche dem Drucke ausgesetzt wird, derart, dass die Zusammendrückung 0,061 cm in der Minute beträgt.

Scherversuch, parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 6,35 cm. An einem Ende unterschnitten, um eine Scherung über eine Fläche von 5,08 × 5,08 cm zu gestatten; Scherung 0,038 cm in der Minute.

Zugversuch senkrecht zur Faserrichtung.—Muster so wie oben. Kreuzweise an jedem Ende gebohrt um die Zugkraft auf eine Fläche von 5,08 × 2,54 cm wirken zu lassen. Zug der Maschine 0,635 cm in der Minute.

Härte.—Muster 5,08 × 5,08 × 15,24 cm. Das notwendige Gewicht um eine Stahlkugel von einem maximalen Querschnitt von 1 cm bis zur Hälfte seines Durchmessers einzudrücken. Bewegung der Maschine 0,635 cm in der Minute.

Spaltung parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 9,525 cm. Kreuzweise an einem Ende gebohrt für die Fassung des Musters zur Spaltung über eine Weite von 5,08 cm und 7,62 cm der Länge nach. Spaltung 0,635 cm in der Minute.

Flessione per urto.—Dimensioni come sopra. Un martello di 22,7 kg cade prima di una altezza di 2,54 cm, poi di 5,08 cm ecc. fino a 25,4 cm; da 25,4 in poi l'aumento di altezza è di 5,08 cm fino a rottura.

Compressione parallela alla fibra.—Dimensioni della provetta, 5,08 × 5,08 × 20,32 cm. Carico finale, spostamento della macchina 0,061 cm al minuto.

Compressione perpendicolare alla fibra.—Dimensioni della provetta 5,08 × 5,08 × 15,24 cm. Il carico è applicato lateralmente a mezzo di una piastra di acciaio di 5,08 cm di larghezza, e questa è disposta nel mezzo del pezzo ad angolo retto rispetto alla lunghezza, per modo che ⅓ della superficie viene sottoposta a pressione. Lo spostamento della macchina deve essere di 0,061 cm al minuto.

Taglio nel senso della fibra.—Dimensioni della provetta 5,08 × 5,08 × 6,35 cm. Adattato ad una estremità in maniera da permettere il taglio sopra un'area di 5,08 × 5,08 cm. Spostamento della macchina 0,038 cm al minuto.

Trazione perpendicolare al senso della fibra.—Dimensioni come sopra. Forato in croce ad ogni estremità per fare agire lo sforzo sopra una superficie di 5,08 × 2,54 cm. Spostamento della macchina 0,635 cm al minuto.

Durezza.—Dimensioni della provetta, 5,08 × 5,08 × 15,24 cm. Carico necessario per far penetrare fino a metà spessore una sfera di acciaio avente una sezione massima di 1 cm.[2] Spostamento della macchina 0,635 cm al minuto.

Sfaldatura parallela alla fibra.—Dimensioni delle provette 5,08 × 5,08 × 9,525. Forato a croce ad una estremità per sollecitare la provetta allo scorrimento per una larghezza di 5,08 cm e una lunghezza di 7,62 cm. Spostamento della macchina 0,635 cm al minuto.

HÖLZER DER PHILIPPINEN

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Einleitung

Dichte und Festigkeit von fünf Hölzern des Handels sind bestimmt worden. Die angewendeten Prüfungsmethoden und der Vorgang bei der Darstellung der Ergebnisse sind dieselben, welche von U. S. Forest Products Laboratory angewandt werden und schon oben verzeichnet sind. Es sind daher die Ergebnisse am Ende der Tafel 1 (unten) angegeben.

CANADISCHE HÖLZER

Eine Anzahl der in der Liste Tabelle 1 unten vorhandenen Arten sind ebenso vom Canadian Forest Products Laboratory untersucht worden, indem Proben von in Canada gewachsenen Bäumen, verwendet wurden. Soweit man ein abschliessendes Urteil abgeben kann, sind diese Hölzer im wesentlichen von gleicher Eigenschaft wie diejenigen, die in den Vereinigten Staaten gewachsen sind.

LEGNI DELLE FILIPPINE

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Introduzione

Sono state determinate densità e tenacità di cinque legni del commercio. I metodi di saggio adoperati e la rappresentazione dei risultati sono gli stessi impiegati dall' U. S. Forest Products Laboratory (*v.* sopra). I risultati sono stati perciò incorporati nella Tabella 1 e riportati in fondo.

LEGNI DEL CANADÀ

Un certo numero delle specie elencate nella Tabella 1 in basso è stato esaminato dal Canadian Forest Products Laboratory, il quale ha eseguito i saggi su campioni di alberi cresciuti nel Canadà. Questi legni hanno dimostrato di possedere proprietà eguali a quelle delle stesse specie crescente negli Stati Uniti.

TABLE 1.—STRENGTH AND RELATED PROPER-

Index No.	Botanical name: Family	Botanical name: Genus and species	Common name	Place of growth of material tested*	Seasoning condition	Density based on weight when oven-dry and volume: When oven-dry D_o	When green (D_g)	When air-dry (D_a)	Moisture content
						g/cm³			% of oven dry-weight

I. Equations expressing strength proper-

1	2	3	4	5	6	7	8	9	10

Green ....

Green to oven-dry ....

Air-dry ....

II. Values as determined by tests—strength and shrink-

1	2	3	4	5	6	7	8	9	10
1	*Aceraceae*	*Acer macrophyllum*	Maple, bigleaf	Washington	Green	0.513	0.440		72
					Air-dry			0.483	12
2		*Acer nigrum*	Maple, black	Indiana	Green	0.620	0.520		65
					Air-dry			0.568	12
3		*Acer pennsylvanicum*	Maple, striped	Vermont	Green		0.438		35
					Air-dry			0.464	12
4		*Acer rubrum*	Maple, red	Wisconsin, Pennsylvania,	Green	0.546	0.488		63
				New Hampshire	Air-dry			0.538	12
5		*Acer saccharinum*	Maple, silver	Wisconsin	Green	0.506	0.439		66
					Air-dry			0.470	12
6		*Acer saccharum*	Maple, sugar	Ind., Pa., Vt., Wis.	Green	0.676	0.568		57
					Air-dry			0.630	12
7	*Anacardiaceae*	*Rhus hirta*	Sumach, staghorn	Wisconsin	Green		0.449		45
					Air-dry			0.473	12
8		*Rhus metopium*	Poisonwood	Florida	Green	0.553	0.511		71
					Air-dry			0.533	12
9	*Aquifoliaceae*	*Ilex opaca*	Holly	Tennessee	Green	0.606	0.503		82
					Air-dry			0.569	12
10	*Betulaceae*	*Alnus rubra*	Alder, red	Washington	Green	0.434	0.368		98
					Air-dry			0.407	12
11		*Betula alaskana*	Birch, Alaska	Alaska	Green	0.594	0.488		58
					Air-dry				
12		*Betula lenta*	Birch, sweet	Pennsylvania	Green	0.714	0.601		53
				New Hampshire	Air-dry			0.654	12
13		*Betula lutea*	Birch, yellow	Wis., Pa.	Green	0.668	0.550		68
					Air-dry			0.617	12
14		*Betula papyrifera*	Birch, paper	Wis., N. H.	Green	0.600	0.484		65
					Air-dry			0.552	12
15		*Betula populifolia*	Birch, gray	New Hampshire	Green	0.552	0.448		63
					Air-dry			0.506	12
16		*Carpinus caroliniana*	Beech, blue	Massachusetts	Green	0.717	0.575		48
					Air-dry			0.694	12
17		*Ostrya virginiana*	Hornbeam	Wisconsin	Green	0.762	0.632		52
					Air-dry			0.708	12
18	*Burseraceae*	*Bursera simaruba*	Gumbo, limbo	Florida	Green	0.320	0.305		99
					Air-dry			0.307	12
19	*Caprifoliaceae*	*Sambucus glauca*	Elderberry, blue	Oregon	Green	0.570	0.464		124
					Air-dry			0.518	12
20	*Combretaceae*	*Conocarpus erecta*	Buttonwood, Florida	Florida	Green	0.851	0.694		47
					Air-dry			0.709	12

*All material tested was grown in the United States. The State or States in which grown are listed in column 5.

ties of Certain North American Woods

Shrinkage from green to oven-dry condition			Static bending						Impact bending 22.7 kg hammer				Compression parallel to grain			Compression perpendicular to grain	Shear		Tension perpendicular to grain		Hardness: load to embed a steel ball of 1 sq. cm maximum cross section to one-half its diameter			Cleavage	
In volume	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Total work	Fiber stress at elastic limit	Modulus of elasticity	Work to elastic limit	Height of drop causing complete failure	Fiber stress at elastic limit	Maximum crushing strength	Modulus of elasticity	Compression perpendicular to grain	Radial	Tangential	Radial	Tangential	End	Radial	Tangential	Radial	Tangential
% of dimension when green			kg/mm²			kg-mm/mm³			kg/mm²		kg-mm/mm³	m	kg/mm²			kg/mm²	kg/mm²		kg/mm²		kg			kg/mm of width	

ties and shrinkage in terms of density

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
....	...	...	$F = 7.17D_g^{1.25}$	$F = 12.4D_g^{1.25}$	$F = 1660D_g^{1.00}$	$F = 0.00172D_g^{1.50}$	$F = 0.0250D_g^{1.75}$	$F = 0.0724D_g^{2.00}$	$F = 16.7D_g^{1.25}$	$F = 2070D_g^{1.00}$	$F = 0.00745D_g^{1.50}$	$F = 2.90D_g^{1.75}$	$F = 3.69D_g^{1.00}$	$F = 4.73D_g^{1.00}$	$F = 2050D_g^{1.00}$	$F = 2.11D_g^{2.25}$	$F = 1.73D_g^{1.25}$	$F = 1.85D_g^{1.25}$	$F = 1.27D_g^{2.00}$	$F = 1.62D_g^{2.00}$	$F = 1700D_g^{2.25}$	$F = 1530D_g^{2.25}$	$F = 1570D_g^{2.25}$	$F = 19.3D_g^{2.00}$	$F = 22.5D_g^{2.00}$
$S = 26.5D_g^{1.00}$	$S = 9.10D_g^{1.00}$	$S = 16.3D_g^{1.00}$																							
....	...	...	$F = 11.74D_d^{1.25}$	$F = 18.1D_d^{1.25}$	$F = 1969D_d^{1.00}$	$F = 0.00389D_d^{1.50}$	$F = 0.0228D_d^{1.75}$	$F = 0.0511D_d^{2.00}$	$F = 21.9D_d^{1.25}$	$F = 2380D_d^{1.00}$	$F = 0.0112D_d^{1.50}$	$F = 2.40D_d^{1.75}$	$F = 6.15D_d^{1.00}$	$F = 8.58D_d^{1.00}$	$F = 2380D_d^{1.00}$	$F = 3.26D_d^{2.25}$	$F = 2.22D_d^{1.25}$	$F = 2.40D_d^{1.25}$	$F = 1.31D_d^{2.00}$	$F = 1.60D_d^{2.00}$	$F = 2180D_d^{2.25}$	$F = 1690D_d^{2.25}$	$F = 1730D_d^{2.25}$	$F = 20.4D_d^{2.00}$	$F = 22.9D_d^{2.00}$

age values expressed in percentage of equation values

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
99	92	99	119	116	105	144	102	76	100	114	90	85	103	109	97	118	120	123	143	154	129	118	114	134	150
			99	104	108	91	87	68		98		107	122	103	87	104	123	145	101	120	147	120	115	125	158
101	102	109	90	101	108	77	112	117	96	99	95	132	104	93	88	107	97	103	118	136	109	112	101	128	140
			101	105	102	103	104	106	88	95	83	112	90	97	92	97	108	118	65	128	128	115	110	109	105
105			99	115	104	97	130	67	103	141	75	134	79	99	109	106	123	130			86	95			
			80	109	103	62	135	117	95	88	102	108		97		97		108			113	104			
101	89	102	92	107	120	78	113	97	101	103	101	97	95	100	123	85	101	107	126	119	105	104	100	100	106
			111	112	109	129	115	128	106	108	108	99	98	99	92	107	119	128	107	160	120	101	101	147	135
103	75	100	85	92	91	86	131	112	80	79	84	107	84	84	83	97	111	120	140	144	115	111	110	133	135
			98	90	87	111	95	90	103	84	137	99	108	93	70	110	114	127	83	131	133	99	106	122	131
99	92	99	101	108	115	99	100	109	104	106	104	95	105	105	102	95	106	116	110	123	102	102	98	110	119
			101	108	104	102	114	95	119	121	117	93	102	103	94	108	125	135	120	102	111	109	112	121	150
			80	90	76	92	123	204						89		97					109	107	103		
			123	102	91	167	97	119						106		121					100	105	91		
85	89	86	71	67	34	153	50	27	78	76	85	43	39	63	96	136	73	91	68	64	49	43	36	67	53
			71	91	86	59	59	31						74		72									
121	98	116	77	87	75	83	101	127	88	71	116	148	74	78	58	95	96	113	102	128	108	108	109	105	136
			75	81	70	83	89	64	82	72	101	93	71	83	60	89	94	118	123	85	107	95	100	99	
129	129	122	127	129	134	130	129	101	117	129	108	110	136	119	135	99	104	107	148	136	141	119	125	128	143
			130	119	120	133	125	74	115	115	117	102	130	120	143	90	97	109	102	140	156	117	125	130	136
128			90	98	117	72	113	136	101	103	103	113	77	92	96	73	84	92	48	33	74	85	80	67	59
98	118	87	88	100	116	83	107	116	83	114	64	102	85	92	127	62	90	94	58	59	90	87	90	71	69
			103	111	118	95	117	76	137	135	126	105	106	107	106	76	122	116	112	98	106	105	98	119	115
115	148	100	94	103	119	81	133	128	103	106	105	100	95	93	106	58	92	93	80	74	84	85	82	89	82
			118	120	122	120	141	123	115	115	114	136	123	112	98	76	92	102	102	106	90	98	94	77	116
126	143	109	72	89	102	55	162	180	84	94	74	153	66	73	83	58	80	82	67	65	64	81	86	79	73
			89	102	103	83	139	157	84	96	74	115	81	87	96	63	80	78			72	95	94	149	142
124	127		49	76	38	64	159	182	85	87	82	211	42	62	33	61					71	75	96		
			76	89	80	73	110	162	78	98	61	122	69	79	88	95					66	100	90		
125			62	77	73	58	141	177	85	85	86	245	46	69	62	85	98	85	76	32	83	95	95	73	59
			36	74	55	24	213	217	52	61	46		51	66	48	95	112	116	116		76	108	105	125	102
111	144	92	78	86	77	84	83	96	79	98	65	143	78	84	73	69	96	95	63	48	87	98	94	77	66
			89	87	86	95	80	85	70	80	62	94	93	94	70	74	93	78			103	111	110		
106	82	72	84	82	77	110	79	42	93	70	128	92	49	73	56	139	103	100	187	210	111	96	95	166	140
			88	81	86	92	72	45	88	98	86	73	67	85	95	177	110	105	204	170	111	106	101	169	172
126	105	118	86	97	82	94	95	156	87	92	85	128	100	97	109	98	116	107	144	113	114	119	117	151	104
			79	83	71	80	98		77	70	87	108	76	82	81	73					79	94	102		
79	86	75	70	66	73	71	33	33	93	79	110	66	84	88	118	86	75	77	44	51	66	74	74	68	62
			62	60	79	51	34							90		76									

1	2	3	4	5	6	7	8	9	10
21	*Cornaceae*	*Cornus florida*	Dogwood (flowering)	Tennessee	Green	0.796	0.638		62
					Air-dry			0.735	12
22		*Cornus nuttallii*	Dogwood, Pacific	Oregon	Green	0.701	0.578		52
					Air-dry			0.644	12
23		*Nyssa aquatica*	Gum, tupelo	Louisiana, Missouri	Green	0.524	0.455		97
					Air-dry			0.496	12
24		*Nyssa sylvatica*	Gum, black	Tennessee	Green	0.552	0.462		55
					Air-dry			0.507	12
25	*Ebenaceae*	*Diospyros virginiana*	Persimmon	Missouri	Green	0.776	0.639		59
					Air-dry			0.748	12
26	*Ericacae*	*Arbutus menziesii*	Madroña	Oregon, California	Green	0.694	0.575		69
					Air-dry			0.653	12
27		*Kalmia latifolia*	Laurel, mountain	Tennessee	Green	0.744	0.616		62
					Air-dry			0.684	12
28		*Oxydendrum arboreum*	Sourwood	Tennessee	Green	0.593	0.504		69
					Air-dry			0.550	12
29		*Rhododendron maximum*	Rhododendron, great	Tennessee	Green	0.601	0.501		99
					Air-dry			0.576	12
30	*Fagaceae*	*Castanea dentata*	Chestnut	Tennessee, Maryland	Green	0.454	0.396		122
					Air-dry			0.433	12
31		*Castanopsis chrysophylla*	Chinquapin, golden	Oregon	Green	0.483	0.417		134
					Air-dry			0.459	12
32		*Fagus grandifolia*	Beech	Ind., Pa.	Green	0.655	0.544		62
					Air-dry			0.624	12
33		*Quercus alba*	Oak, white	La., Ark., Ind.	Green	0.710	0.595		68
					Air-dry			0.683	12
34		*Quercus bicolor*	Oak, swamp white	Indiana	Green	0.792	0.637		74
					Air-dry			0.720	12
35		*Quercus borealis*	Oak, red	La., Ark., Ind., Tenn., N. H.	Green	0.657	0.564		80
					Air-dry			0.628	12
36		*Quercus californica*	Oak, California black	Oregon, California	Green	0.578	0.510		106
					Air-dry			0.571	12
37		*Quercus chrysolepis*	Oak, canyon live	California	Green	0.838	0.702		62
					Air-dry			0.778	12
38		*Quercus coccinea*	Oak, scarlet	Massachusetts	Green	0.709	0.603		65
					Air-dry				
39		*Quercus gambelii*	Oak, Gambel	Arizona	Green	0.701	0.617		61
					Air-dry			0.735	12
40		*Quercus garryana*	Oak, Oregon white	Oregon	Green	0.748	0.644		72
					Air-dry			0.724	12
41		*Quercus laurifolia*	Oak, laurel	Louisiana	Green	0.703	0.564		84
					Air-dry			0.632	12
42		*Quercus macrocarpa*	Oak, bur	Wisconsin	Green	0.671	0.583		70
					Air-dry			0.644	12
43		*Quercus montana*	Oak, chestnut	Tennessee	Green	0.674	0.573		72
					Air-dry			0.658	12
44		*Quercus nigra*	Oak, water	Louisiana	Green	0.685	0.556		81
					Air-dry			0.633	12
45		*Quercus rubra pagodaefolia*	Oak, swamp red	Louisiana	Green	0.708	0.607		78
					Air-dry			0.680	12
46		*Quercus palustris*	Oak, pin	Massachusetts	Green	0.677	0.577		75
					Air-dry				
47		*Quercus phellos*	Oak, willow	Louisiana	Green	0.688	0.556		94
					Air-dry			0.696	12
48		*Quercus prinus*	Oak, swamp chestnut	Louisiana	Green	0.756	0.595		76
					Air-dry			0.674	12
49		*Quercus rubra*	Oak, southern red	Louisiana	Green	0.624	0.521		90
					Air-dry			0.588	12
50		*Quercus stellata*	Oak, post	Arkansas, Louisiana	Green	0.738	0.596		69
					Air-dry			0.675	12
51		*Quercus velutina*	Oak, black	Arkansas, Wisconsin	Green	0.669	0.564		78
					Air-dry			0.610	12
52		*Quercus virginiana*	Oak, live	Florida	Green	0.977	0.810		50
					Air-dry			0.888	12
53	*Hamamelidaceae*	*Hamamelis virginiana*	Witch-hazel	Tennessee	Green	0.714	0.558		70
					Air-dry			0.614	12
54		*Liquidambar styraciflua*	Gum, red	Missouri	Green	0.530	0.441		81
					Air-dry			0.487	12
55	*Hippocastanaceae*	*Aesculus octandra*	Buckeye, yellow	Tennessee	Green	0.383	0.326		141
					Air-dry			0.363	12
56	*Juglandaceae*	*Hicoria alba*	Hickory, mockernut	Pa., Miss.	Green		0.642		60
					Air-dry			0.725	12
57		*Hicoria aquatica*	Hickory, water	Mississippi	Green		0.606		80
					Air-dry			0.621	12
58		*Hicoria cordiformis*	Hickory, bitternut	Ohio	Green		0.604		66
					Air-dry			0.663	12
59		*Hicoria glabra*	Hickory, pignut	W. Va., Miss., Ohio, Pa.	Green		0.661		54
					Air-dry			0.754	12
60		*Hicoria laciniosa*	Hickory, bigleaf shagbark	Ohio, Miss.	Green		0.622		61
					Air-dry			0.692	12
61		*Hicoria myristicae formis*	Hickory, nutmeg	Mississippi	Green		0.556		74
					Air-dry			0.605	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
117	122	109	82	87	78	90	130	127	52	44	65	111		84		95	104	106			104	115	112		
			82	87	75	94	103	99	71	66	77	79		89		85		103			103	119	114		
112	121	101	81	92	80	86	124	113	81	89	77	129	75	93	91	100	97	105	114	102	105	101	95	81	90
			78	71	82	74	72	107	58	76	45	76	77	99	91	99	90	96		123	108	101	98	71	95
103	103	103	110	111	97	132	92	94	101	105	100	104	115	110	102	117	119	132	147	165	127	120	123	117	160
			107	91	91	132	73	63	97	91	107	82	101	101	88	117	114	122	172	134	125	111	119	102	136
113	105	103	103	105	95	120	87	87	108	99	121	102	100	98	71	114	107	120	134	128	120	110	104	130	136
			104	88	84	133	62	85	111	96	126	74	80	92	77	118	93	100	97	92	121	104	96	93	120
108	129	104	96	99	91	109	80	78	89	94	83	78	90	97	81	102	97	106	82	99	91	101	104	82	88
			98	101	98	103	81	87	86	95	84	64	98	105	81	106	92	104	98	116	106	120	122	99	81
114	104	127	91	85	65	135	82	56	85	75	100	91	77	86	74	91	111	110	124	103	104	98	92	112	108
			76	70	68	87	30	37	56	68	52	49	74	90	66	95	83	107			106	107	102	105	87
88	100	87	104	88	64	172	81	73	79	61	100	65		103		110	120	119			112	114	112		
			84	71	64	114	61	52	75	66	84	83		73		94					106	115	112		
113	137	107	101	102	110	94	92	79	106	106	108	110	102	95	128	106	105	109	140	133	107	101	99	131	136
			107	96	100	112	96	100	117	101	135	114	95	95	168	92	109	89	85	76	110	98	96	112	95
122	137	106	107	92	74	160	114	125		69		76		103		140	114	117			127	124	116		
			82	88	70	99	99	93		65		52		95		111									
109	94	103	95	101	99	97	100	106	106	107	108	104	98	92	84	103	107	93	148	124	115	99	102	137	124
			106	97	102	119	87	93	100	95	104	89	100	104	93	111	99	90	123	114	99	96	96	116	113
119	121	109	123	118	103	165	123	113	110	102	121	126	87	107	125	117	115	122	149	121	140	139	113	113	116
			130	113	98	194	114	125	93	89	98	122	98	103	93	87	97	109			102	120	106	131	
112	96	119	94	99	96	101	102	90	94	91	98	103	89	89	82	80	97	105	116	130	100	95	94	105	130
			93	102	96	100	97	106	103	98	109	85	84	91	93	78	106	106	127	99	82	90	88	103	113
100	98	93	88	90	89	97	81	80	86	90	85	90	95	88	73	89	90	98	99	110	96	102	96	94	107
			79	95	93	73	89	76	88	92	84	76	72	89	82	67	98	106	56	105	75	88	84	61	96
104	95	102	92	98	106	85	89	89	98	109	89	96	103	101	80	87	86	93	104	103	89	99	87	97	105
			91	103	102	86	105	130	107	101	115	92	88	96	88	66	85	99	66	87	73	88	92	68	82
90	78	89	81	96	101	71	101	107	91	101	84	106	78	91	95	92	99	96	118	113	103	110	104	114	114
			91	99	103	85	101	126	101	97	106	103	80	89	96	78	100	98	92	102	94	101	95	80	88
90	78	80	77	81	61	116	80	62	79	77	87	84	70	81	57	136	104	103	123	136	111	117	111	104	122
			75	69	63	100	53	40	57	61	57	44	67	84	63	113	92	92	107	122	88	108	102	76	104
87	125	124	96	93	81	119	75	66	73	86	62	76	109	99	76	108	98	108	86	104	94	104	99	80	100
			78	70	75	87	46	43	58	66	51	60	94	99	77	87	95	99	106		95	119	112	89	87
86	84	98	83	111	103	71	102	119	94	111	80	115	90	100	93	108	106	102	99	89	98	109	110	99	97
76	73	71	57	61	33	104	74	72	62	46	83	16	33	71	28	109	103	116	104	89	96	110	112	81	85
			47	49	33	68	47	30	66	86	52	39		58		90	72			47	86	84	70	60	
78	71	85	78	76	52	120	83	76	75	66	87	92	74	82	56	123	105	117	96	121	103	114	104	79	104
			60	60	54	69	53	49	57	63	55	52	65	76	52	96	87	98	42	105	81	97	87	34	81
127	76	103	90	92	104	84	86	75	88	109	76	93	92	84	91	86	94	95	110	123	99	107	104	94	110
			82	88	95	74	82	112	84	107	69	93	85	92	113	81	99	111	91	99	72	92	89	72	73
82	83	93	69	80	64	82	77	87	82	70	98	99	75	84	50	94	102	106	116	114	104	109	109	106	108
			67	69	57	85	65	61	82	69	98	64	62	78	58	88	89	106	58	93	80	97	99	48	78
110	106	103	90	91	101	85	70	66	101	105	98	81	96	91	91	76	94	96	96	106	91	94	88	86	110
			92	88	86	102	72	66	101	113	92	89	83	86	97	58	70	84		135	68	80	76	47	95
111	82	102	112	105	118	113	87	99	102	123	86	95	109	100	108	96	102	101	115	138	105	112	109	110	134
			94	106	114	82	148	106	106	115	101	103	70	89	147	76	108	104	108	115	82	93	84	82	109
102	94	109	118	114	125	115	99	98	96	128	76	113	118	113	114	97	97	96	103	107	104	115	108	99	110
			109	114	121	102	112	93	124	119	136	102	109	107	118	81	105	103	85	93	78	95	94	65	76
95	81	101	77	94	97	67	103	122	100	114	90	110		94		102	101	102	110	122	93	116	101	115	124
128	98	106	89	87	98	87	69	67	81	101	66	86	85	80	86	95	96	99		119	103	108	106	113	110
			89	90	98	84	87	110	80	93	84	84	74	84	118	70	65	95		120	68	79	100		123
123	109	95	90	92	96	89	89	96	83	108	65	98	97	88	87	76	91	98	92	92	95	106	102	85	104
			71	88	94	56	74	60	99	113	90	86	73	89	93	72	114	102	69	79	65	82	79	47	76
118	96	102	93	88	93	101	70	56	86	99	78	80	80	86	89	98	92	74	98	75	106	107	111	99	80
			70	84	91	59	74	54	96	87	103	70	57	86	165	77	66	102	67	77	71	96	92	70	96
102	100	101	93	87	77	117	77	65	87	94	83	94	90	87	71	114	93	98	107	108	100	108	104	93	104
			74	84	80	74	81	118	92	87	96	96	66	80	88	93	93	94	64	97	68	95	82	65	90
95	88	105	91	95	88	120	94	88	97	88	108	95	94	91	86	106	102	94	140	129	97	114	110	122	126
			87	99	96	83	100	103	84	88	84	102	88	88	92	76	110	111	103	108	87	102	93	87	101
68	89	71	107	88	82	143	50	38	94	82	109	71	97	99	147	135	109	116	68	84	72	91	86	65	77
			61	83	79	48	72	72	79	77	83	43	72	82	131	99	94	94	58	65	85	88	96	45	62
127			101	97	84	127	152	176	108	83	143	97		90		77	89	92			101	106	107		
			102	112	85	126	155							83		92					120	128	123		
128	130	138	101	107	110	114	111	106	116	116	126	121	101	95	111	96	113	121	129	127	107	96	97	137	150
			119	114	109	142	123	92	135	117	158	119	100	98	99	95	118	121	148	169	101	95	92	114	150
138	117	147	105	111	127	91	108	86	111	119	105	112	95	93	104	87	97	114	136	153	119	107	101	132	155
			110	105	116	112	109	81	116	109	129	96	100	96	124	96	101	106	202	181	98	93	93	122	168
105	135	105	107	108	102	110	160	172	110	100	123	167	115	103	81	90	86	89							
			108	112	110	103	123	174	98	100	99	142		102		96	84	76							
			109	113	109	112	127	139	108	98	121	118	101	114	109	112	105	106							
			111	126	117	110	136	149		111		127	101	116	106	122		94							
			100	109	98	107	135	199	124	93	170	140	136	112	92	102	87	95							
			94	112	97	93	116	215	128	114	147	143		113		115	96								
102	120	107	101	111	106	102	183	191	119	94	154	161		108		96	89	92							
			97	112	108	92	154	201	116	108	127	127		103		102	96	94							
116	136	124	99	108	91	113	192	220	108	88	135	208	84	93	80	97	82	86							
			85	113	98	74	138	195	116	100	153	175		97		112	105	102							
			99	107	98	105	181	182	112	87	139	132	123	106	87	118	86	83							
			91	122	101	80	188							95		133	110								

1	2	3	4	5	6	7	8	9	10
62		*Hicoria ovata*	Hickory, shagbark	Miss., Ohio, W. Va., Pa.	Green		0.637		60
					Air-dry			0.724	12
63		*Hicoria pecan*	Hickory, pecan	Missouri	Green	0.694	0.601		63
					Air-dry			0.666	12
64		*Juglans cinerea*	Butternut	Wisconsin, Tennessee	Green	0.404	0.359		104
					Air-dry			0.383	12
65		*Juglans nigra*	Walnut, black	Kentucky	Green	0.562	0.513		81
					Air-dry			0.552	12
66		*Juglans rupestris*	Walnut, Mexican	Arizona	Green	0.613	0.532		67
					Air-dry			0.570	12
67	*Lauraceae*	*Sassafras sassafras*	Sassafras	Tennessee	Green	0.473	0.424		67
					Air-dry			0.451	12
68		*Umbellularia californica*	Myrtle, Oregon	Oregon	Green	0.589	0.512		71
					Air-dry			0.556	12
69	*Leguminosae*	*Gleditsia triacanthos*	Locust, honey	Indiana, Missouri	Green	0.666	0.596		63
					Air-dry			0.636	12
70		*Robinia pseudacacia*	Locust, black	Tennessee	Green	0.708	0.659		41
					Air-dry			0.694	12
71	*Magnoliaceae*	*Liriodendron tulipifera*	Poplar, yellow	Tennessee, Kentucky	Green	0.427	0.376		64
					Air-dry			0.401	12
72		*Magnolia acuminata*	Magnolia, cucumber	Tennessee	Green	0.516	0.440		80
					Air-dry			0.480	12
73		*Magnolia fraseri*	Magnolia, Fraser's	Tennessee	Green	0.477	0.400		89
					Air-dry			0.446	12
74		*Magnolia grandiflora*	Magnolia, evergreen	Louisiana	Green	0.530	0.460		117
					Air-dry			0.502	12
75	*Moraceae*	*Toxylon pomiferum*	Orange, osage	Indiana	Green	0.838	0.761		31
					Air-dry				
76		*Ficus aurea*	Fig, golden	Florida	Green		0.438		88
					Air-dry			0.444	12
77	*Myrtaceae*	*Eucalyptus globulus*	Gum, blue	California	Green	0.796	0.625		79
					Air-dry			0.750	12
78		*Eugenia garberi*	Stopper, Garber's	Florida	Green	0.918	0.831		40
					Air-dry			0.877	12
79	*Oleaceae*	*Fraxinus americana*	Ash, white	Ark., N. Y., W. Va.	Green	0.638	0.542		42
					Air-dry			0.593	12
80		*Fraxinus biltmoreana*	Ash, Biltmore white	Tennessee	Green	0.584	0.507		42
					Air-dry			0.550	12
81		*Fraxinus pennsylvanica lanceolata*	Ash, green	Louisiana, Missouri	Green	0.610	0.526		48
					Air-dry			0.566	12
82		*Fraxinus nigra*	Ash, black	Wisconsin, Michigan	Green	0.526	0.457		84
					Air-dry			0.493	12
83		*Fraxinus oregona*	Ash, Oregon	Oregon	Green	0.575	0.497		48
					Air-dry			0.550	12
84		*Fraxinus profunda*	Ash, pumpkin	Missouri	Green	0.551	0.485		51
					Air-dry			0.520	12
85		*Fraxinus quadrangulata*	Ash, blue	Kentucky	Green	0.603	0.532		39
					Air-dry			0.568	12
86	*Palmaceae*	*Sabal palmetto*	Palmetto, cabbage	Florida	Green	0.453	0.372		133
					Air-dry			0.387	12
87	*Pinaceae*	*Abies amabilis*	Fir, silver	Washington	Green	0.415	0.351		66
					Air-dry			0.385	12
88		*Abies balsamea*	Fir, balsam	Wisconsin	Green	0.414	0.335		117
					Air-dry			0.366	12
89		*Abies concolor*	Fir, white	California, New Mexico	Green	0.397	0.348		115
					Air-dry			0.371	12
90		*Abies grandis*	Fir, lowland white	Montana, Oregon	Green	0.419	0.370		94
					Air-dry			0.398	12
91		*Abies lasiocarpa*	Fir, alpine	Colorado	Green	0.321	0.306		47
					Air-dry			0.327	12
92		*Abies magnifica*	Fir, red	California	Green	0.421	0.372		108
					Air-dry			0.388	12
93		*Abies nobilis*	Fir, noble	Oregon	Green	0.403	0.351		36
					Air-dry			0.375	12
94		*Chamaecyparis lawsoniana*	Cedar, Port Orford	Oregon	Green	0.440	0.399		43
					Air-dry			0.416	12
95		*Chamaecyparis nootkatensis*	Cedar, Alaska	Oregon	Green	0.439	0.399		40
					Air-dry			0.422	12
96		*Chamaecyparis thyoides*	Cedar, southern white	New Hampshire, North Carolina	Green	0.352	0.310		35
					Air-dry			0.323	12
97		*Juniperus pachyphloea*	Juniper, alligator	Arizona	Green	0.545	0.477		40
					Air-dry			0.511	12
98		*Juniperus virginiana*	Cedar, eastern red	Vermont	Green	0.492	0.442		35
					Air-dry			0.471	12
99		*Larix laricina*	Tamarack	Wisconsin	Green	0.558	0.491		52
					Air-dry			0.528	12
100		*Larix occidentalis*	Larch, western	Montana, Washington	Green	0.587	0.482		58
					Air-dry			0.520	12
101		*Libocedrus decurrens*	Cedar, incense	Oregon, California	Green	0.365	0.346		108
					Air-dry			0.368	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
99	121	101	101	110	104	103	146	181	106	96	119	143	102	107	93	96	119	92							
			97	119	107	91	140	206	93	98	92	124		106		98	100	94							
85	89	91	96	104	96	104	100	117	97	98	100	113	96	99	83	101	108	112	97	86	107	125	116	95	103
			92	89	93	99	86	98	93	95	97	95	85	100	86	120	114	105		109	103	122	123	131	128
107	100	103	101	109	114	100	137	146	110	114	109	124	103	100	102	91	103	110	168	157	109	112	115	146	151
			116	105	110	128	137	189	120	119	126	135	115	112	107	109	119	125	134	150	105	109	117	113	128
83	111	85	120	123	117	129	132	123	115	117	115	104	133	124	117	90	111	108	106	105	115	120	116	123	110
			126	121	109	173	92	93	111	102	129	101	124	116	110	108	84	94	152	72	84	105	100	103	72
76	92	53	73	99	73	78	108	159	91	78	110	122		84		105								86	
			102	113	94	114	93	58	72	80	65	57		99											
91	103	90	102	99	91	119	90	122	104	94	121	145	108	95	70	106	118	101	161	125	113	110	101	157	131
			102	96	89	120	110	181	92	86	110	138	84	89	67	140	109	98	165	121	82	108	98	127	119
88	60	96	87	86	59	138	153	160	80	64	105	161	73	88	55	121	113	117	132	153	122	132	132	109	166
			69	65	61	83	68	50	72	68	81	89	77	86	54	116	119	124	142	133	123	124	133	113	110
68	78	67	104	110	92	125	88	94	94	97	95	102	105	110	84	152	128	121	123	130	124	140	121	118	116
			95	103	93	101	92	129	88	86	94	109	100	100	80	139	125	121	84	126	108	126	110	80	94
56	73	64	144	131	119	182	90	100	129	122	138	80	181	153	100	122	132	101	94	81	113	113	123	72	85
			122	119	106	148	108	149	107	109	105	114	125	121	157	112	116	130	72	57	75	99	108	55	57
123	118	114	112	103	122	111	85	61	122	117	132	88	100	95	138	100	93	105	136	169	93	92	88	121	146
			116	113	134	106	105	81	137	134	139	105	100	111	157	101	103	109	138	174	93	95	95	134	155
116	130	122	115	117	150	93	118	108	108	129	94	111	119	106	129	87	102	115	114	106	101	98	93	114	116
			125	123	135	112	138	127	121	133	111	134	115	111	137	81	97	112	126	161	106	97	98	107	99
123	122	115	103	109	126	89	115	99	113	122	107	100	107	97	113	87	102	102	136	138	122	113	118	137	139
			114	109	113	119	128	113	124	124	123	116	104	102	131	85	94	105	163	173	108	104	102	133	141
101	129	88	93	101	101	88	167	167	98	103	97	184	91	87	97	110	104	111	126	151	121	126	121	115	159
			98	105	101	100	131	79	103	96	112	101	80	91	120	110	122	105	143	143	126	130	127	165	122
44			106	109	74	156	172	170	92	67	126	169	99	113	60	139					91	126	94		
			86	93	57	130	79	76						89		138					106	114	105		
			64	77	65	64	88	77						82											
135	133	150	134	114	135	138	89	93	107	131	89	80	148	124	126	98	99	119	68	89	101	118	108	74	83
			100	93	114	96	63	57	95	107	87	72	134	112	119	72	57	103			67	82	77		
60	83	67	96	107	99	107	83	67	102	81	13	67	90	110	94	124	92	87	69	61				15	
			89	72	82	113	42	67	36	44	30	14	67	87	78	87						104	82		
90	94	81	111	117	113	115	118	118	111	101	123	100	120	111	100	105	121	111	119	107	111	113	110	108	108
			112	117	107	121	122	118	108	100	120	103	114	104	94	102	130	112	149	102	122	116	114	123	87
93	91	83	126	123	111	149	106	102	117	111	129	86	133	116	101	135	120	107	110	95	118	115	116	119	109
			118	109	104	139	103	121	113	106	126	121	119	114	99	128	119	98	128	100	130	123	113	117	107
89	96	83	115	119	112	123	102	99	107	95	122	94	128	118	99	128	116	105	117	92	109	107	109	114	101
			109	113	105	117	113	96	108	104	112	89	103	103	100	127	130	115	124	88	124	121	109	116	112
126	119	104	67	90	96	56	134	124	81	78	76	113	60	75	78	84	94	88	156	85	92	90	86	147	84
			106	120	116	85	160	186	91	109	91	131	101	101	103	101	130	105	142	133	119	105	116	139	120
100	91	100	99	103	96	108	116	112	90	103	81	115	105	105	115	105	115	109	119	112	110	111	112	102	111
			89	105	88	96	127	111	91	103	82	98	87	92	87	130	119	120	130	105	116	116	123	130	100
93	84	80	108	106	91	132	93	77	91	84	103	97	111	103	78	168	123	112	138	103	120	117	108	131	126
			89	98	88	94	78	67	100	91	115	77	84	92	66	170	133	110	184	100	131	118	112	155	114
83	81	75	122	119	98	155	125	137	103	88	119	113	126	117	84	275	139	128	100	101	126	124	124	100	111
			99	110	88	115	120	147	120	108	135	120	111	102	72	149	122	129	78		129	126	120	105	116
253			64	73	55	82	64	96	72	48	112	73	58	69	33	58					83				
			59	60	51	72	73	125	65	58	76	90	25	47	74	32					53				
150	141	172	127	118	151	120	105	101	121	146	100	115	128	112	150	102	100	95	82	104	103	91	101	102	99
			123	122	142	110	155	160	121	120	128	133	131	120	140	93	133	93		86	113	98	100	99	124
121	93	120	114	108	122	111	90	67	113	118	110	95	118	106	129	82	96	93	81	72	91	97	103	102	94
			111	105	122	106	91	128	88	104	76	124	127	105	128	80	75	79	76	53	105	104	105		
102	100	123	140	120	125	168	90	89	132	135	133	120	120	105	119	134	111	110	115	121	109	103	107	118	120
			133	124	133	140	118	84	118	129	114	114	101	119	118	121	97	99	91	91	142	109	112	93	93
108	94	120	121	118	147	105	89	104	117	129	108	110	137	120	170	106	106	101	87	81	105	96	103	98	89
			112	115	147	92	119	207	123	128	120	150	137	115	152	110	92	89	47	69	112	96	115	140	62
111	89	142	101	110	119	95	98	76	97	109	88	62	105	100	99	148	102	109			108	86	96	127	113
			137	106	98	194	65	68	89	110	75	113	123	102	103	155	127	145			120	103	149	111	106
119	112	113	138	116	121	173	105	89	125	130	117	107		112		137	125	124	113	124	96	104	102	111	123
			136	137	143	138	151		124	136	114	126		112		154	112	98	105	119	190	121	116	98	109
134	141	143	131	121	152	122	105	124	133	138	132	105	127	115	167	119	106	110	83	98	94	87	90	94	110
			136	134	151	129	152	168	122	148	105	139	153	123	169	129	103	104	78	76	133	97	105	72	81
95	128	106	121	110	151	107	104	148	121	135	111	93	128	116	159	94	103	104	60	50	99	92	92	56	57
			138	133	148	135	132	198	130	146	116	137	160	129	144	122	96	102	108	117	111	110	105	98	113
74	53	77	109	110	102	126	134	144	114	113	118	118	114	107	91	109	98	105	87	74	110	92	97	79	73
			117	115	107	139	124	104	114	100	132	135	143	112	98	107	86	93	98	95	102	102	93		
102	100	102	106	116	103	121	127	136	108	102	118	121	103	114	105	141	120	115	97	86	152	121	119	115	104
			116	108	103	117	90	71	100	103	101	102	104	117	122	140	97	104	98	108	139	121	113	106	101
61	63	46	89	94	40	209	137	69	72	49	111	67	96	116	45	181	128	125			136	121	132		56
			75	60	45	138	64		42	44	43	40		66		168	75				123	142	140		
66	78	65	92	110	62	152	175	166	81	81	87	126	112	120	53	182	116	104	82	82	128	124	114	80	73
			57	86	66	57	100		69	56	87	88		102		133			177		101		124	73	115
105	82	92	100	99	107	100	70	120	79	87	72	85	117	105	111	80	87	78	54	49	53	56	53	64	52
			107	101	111	105	67	88	89	91	88	75	107	111	114	91	93	87	79	62	59	68	67	71	61
103	95	102	112	105	118	123	72	77	98	115	103	75	128	117	107	97	93	87	47	48	65	68	69	59	57
			104	103	116	117	78	109	109	121	118	105	151	118	103	100	95	94	54	56	99	93	82	55	45
83	103	100	144	132	103	192	114	64	116	126	111	96	151	135	111	167	127	120	126	107	167	124	125	123	107
			125	109	102	140	95	73	108	107	111	103	151	119	99	152	93	94	95	99	168	118	120		

1	2	3	4	5	9	7	8	9	10
102		*Picea engelmanni*	Spruce, Engelmann	Colorado	Green	0.347	0.312		100
					Air-dry			0.332	12
103		*Picea glauca*	Spruce, white	Wis., N. H.	Green	0.431	0.366		50
					Air-dry			0.391	12
104		*Picea mariana*	Spruce, black	New Hampshire	Green	0.428	0.376		38
					Air-dry			0.402	12
105		*Picea rubra*	Spruce, red	Tennessee, New Hampshire	Green	0.413	0.379		43
					Air-dry			0.406	12
106		*Picea sitchensis*	Spruce, Sitka	Wash., Oregon	Green	0.397	0.355		44
					Air-dry			0.384	12
107		*Pinus banksiana*	Pine, jack	Wisconsin	Green	0.461	0.394		105
					Air-dry			0.428	12
108		*Pinus caribaea*	Pine, slash	Florida	Green	0.756	0.638		40
					Air-dry			0.682	12
109		*Pinus clausa*	Pine, sand	Florida	Green	0.506	0.451		36
					Air-dry			0.481	12
110		*Pinus contorta*	Pine, lodgepole	Wyo., Mont., Colo.	Green	0.434	0.380		65
					Air-dry			0.410	12
111		*Pinus echinata*	Pine, shortleaf	Ark., La.	Green	0.584	0.494		64
					Air-dry			0.542	12
112		*Pinus edulis*	Piñon	Arizona	Green	0.567	0.502		63
					Air-dry			0.530	12
113		*Pinus flexilis*	Pine, limber	New Mexico	Green	0.420	0.374		68
					Air-dry			0.401	12
114		*Pinus jeffreyi*	Pine, Jeffrey	California	Green	0.425	0.371		101
					Air-dry			0.402	12
115		*Pinus lambertiana*	Pine, sugar	California	Green	0.378	0.348		137
					Air-dry			0.360	12
116		*Pinus monticola*	Pine, western white	Montana, Idaho	Green	0.418	0.363		54
					Air-dry			0.385	12
117		*Pinus palustris*	Pine, longleaf	La., Miss., Fla.	Green	0.638	0.551		47
					Air-dry			0.592	12
118		*Pinus ponderosa*	Pine, western yellow	Colo., Wash., Ariz., Cal.,	Green	0.420	0.379		91
				Mont.	Air-dry			0.402	12
119		*Pinus pungens*	Pine, mountain	Tennessee	Green	0.549	0.494		75
					Air-dry			0.523	12
120		*Pinus resinosa*	Pine, red	Wisconsin	Green	0.507	0.440		54
					Air-dry			0.479	12
121		*Pinus rigida*	Pine, pitch	Tennessee	Green	0.542	0.470		85
					Air-dry			0.505	12
122		*Pinus rigida serotina*	Pine, pond	Florida	Green	0.580	0.501		56
					Air-dry			0.539	12
123		*Pinus strobus*	Pine, eastern white	Wis., Minn., N. H.	Green	0.373	0.344		68
					Air-dry			0.362	12
124		*Pinus taeda*	Pine, loblolly	Florida	Green	0.593	0.504		72
					Air-dry			0.550	12
125		*Pseudotsuga taxifolia*	Douglas fir (coast type)	Lewis Co., Chehalis Co.,	Green	0.512	0.448		36
				Clark Co., Wash.; Lane Co., Clatsop Co., Wash. Co., Ore.; Humboldt Co., Cal.	Air-dry			0.482	12
126		*Pseudotsuga taxifolia*	Douglas fir (mountain type)	Johnson Co., Wyo.; Missoula	Green	0.446	0.405		39
				Co., Mont.	Air-dry			0.426	12
127		*Sequoia sempervirens*	Redwood	California	Green	0.436	0.410		113
					Air-dry			0.427	12
128		*Taxodium distichum*	Cypress, southern	Louisiana, Missouri	Green	0.482	0.425		91
					Air-dry			0.458	12
129		*Thuja occidentalis*	Cedar, northern white	Wisconsin	Green	0.315	0.293		55
					Air-dry			0.310	12
130		*Thuja plicata*	Cedar, western red	Montana, Washington	Green	0.344	0.310		39
					Air-dry			0.330	12
131		*Tsuga canadensis*	Hemlock, eastern	Wis., Tenn., N. H.	Green	0.431	0.375		110
					Air-dry			0.398	12
132		*Tsuga heterophylla*	Hemlock, western	Washington, Oregon	Green	0.432	0.377		77
					Air-dry			0.406	12
133		*Tsuga mertensiana*	Hemlock, mountain	Montana	Green	0.480	0.418		70
					Air-dry			0.450	12
134	*Platanaceae*	*Platanus occidentalis*	Sycamore	Indiana, Tennessee	Green	0.539	0.456		83
					Air-dry			0.494	12
135	*Polygonaceae*	*Coccolobis laurifolia*	Plum, pigeon	Florida	Green	0.851	0.771		52
					Air-dry			0.786	12
136	*Rhamnaceae*	*Rhamnidium ferreum*	Ironwood, black	Florida	Green	1.077	1.045		32
					Air-dry			1.147	12
137		*Rhamnus purshiana*	Cascara	Oregon	Green	0.548	0.496		61
					Air-dry			0.516	12
138	*Rhizophoraceae*	*Rhizophora mangle*	Mangrove	Florida	Green	1.063	0.886		39
					Air-dry			0.964	12
139	*Rosaceae*	*Amelanchier canadensis*	Serviceberry	Tennessee	Green	0.791	0.656		48
					Air-dry			0.747	12
140		*Crataegus tomentosa*	Haw, pear	Wisconsin	Green		0.623		63
					Air-dry			0.680	12
141		*Prunus pennsylvanica*	Cherry, wild red	Tennessee	Green	0.425	0.361		46
					Air-dry			0.394	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
125	121	129	103	101	113	102	106	62	105	108	101	94	105	95	109	133	100	100			93	95	99	113	113
			133	122	121	138	119	96	112	116	111	107	115	109	103	156	121	118			108	89	105	158	138
153	112	122	114	110	118	120	99	110	99	110	83	101	107	101	87	87	97	92	76	69	66	78	66	90	81
			116	114	130	117	116	114	100	113	89	111	115	108	138	89	95	92	119	103	107	95	119	100	104
113	121	110	96	103	120	80	115	139	97	130	72	114	81	102	150	53	93	84	36	35	104	103	92	77	64
			107	125	135	94	159	183	134	122	151	118	138	110	144	116	102	95	87		114	112	106	99	68
117	109	126	112	110	132	102	106	93	101	111	92	80	128	104	126	102	102	100	58	85	99	89	93	83	90
			125	122	134	121	125	98	116	119	115	129	139	119	135	95	100	103	107	97	101	96	102	83	90
121	134	128	117	113	147	102	106	141	130	130	136	130	113	108	164	106	109	106	76	89	118	100	103	89	92
			129	124	142	117	150	179	126	137	121	138	122	112	114	132	122	118	122	142	133	109	110	102	117
100	94	102	93	98	99	92	84	127	105	94	127	134	108	97	91	103		91	94	98	83	85	89	106	88
			89	91	103	82	73	75	104	106	107	164		107		124		96	105	103	95	111	104	88	94
75	100	79	97	96	104	113	52	66	96	98	98	70	101	110	115	65	83	70	54	43	51	60	60	51	43
			94	99	110	101	67	59	94	114	80	71	112	119	96	87	98	82	65	49	60	68	76		41
83	95	99	109	115	96	128	108	104	111	89	144	88	108	113	103	112	125	118	102	80	75	83	85	95	
			101	114	106	101	107	105	99	102	103	72	96	119	148	116	84	82	73	52	104	104	100	85	
114	128	108	99	104	120	86	86	82	100	111	92	96	105	102	131	92	93	88	80	69	77	84	88	101	81
			124	112	117	142	102	94	94	100	92	100	128	110	113	124	87	79	102	68	84	93	98	96	79
95	113	101	106	109	124	94	84	140	113	123	108	117	139	114	131	78	92	77	67	65	64	77	83	76	73
			111	111	126	102	87	86	105	124	92	113	127	119	132	100	96	84	80	50	67	81	86	82	55
74	100	63	60	64	55	70	72	88	81	63	110	62	61	76	122	75	86	85	93	85	65	81	83		68
			75	68	77	89	43		60	77	48	39		101		143	99		66		81	96	96		
83	71	84	128	101	90	193	81	61	102	97	108	88	99	96	109	97	102	96	94	92	73	86	82	99	108
			125	112	104	158	103	78	114	109	127	96		111		123	81	74	73	56	85	94	88	148	120
100	130	110	106	97	112	109	75	108	103	103	108	104	104	95	104	110	94	94	90	92	80	91	95	93	99
			138	116	110	180	100	85	125	123	129	141	123	116	100	137	120	116	121	109	102	100	106	129	126
86	91	98	123	107	114	140	96		116	113	120	96	127	108	101	126	102	97	111	108	91	94	100	128	127
			122	112	118	129	101	87	123	118	130	111	145	108	124	126	125	110	126	129	111	104	101	120	123
123	124	125	116	104	136	106	83	139	114	121	113	98	124	108	150	96	90	87	96	96	81	88	90	106	98
			123	123	140	115	146	138	126	137	118	132	145	121	162	101	105	85	101	82	79	86	86	87	88
84	106	83	110	104	125	100	64	98	95	115	79	85	132	118	117	76	96	82	50	44	56	66	67	57	50
			116	116	124	112	83	89	95	111	82	86	135	124	114	99	99	82	59	50	68	79	78	61	47
95	112	102	101	95	108	104	78	92	95	92	102	94	104	93	103	106	91	90	99	97	72	82	81	99	99
			118	112	112	133	101	97	98	103	98	88	120	109	102	125	113	111	120	124	91	94	93	110	112
83	76	84	106	103	109	111	78	110	103	108	103	87	114	106	97	91	96	86	75	56	62	72	70	76	65
			108	104	106	114	84	86	104	105	107	95	90	110	118	115	87	78			66	80	73	62	58
98	115	100	102	101	133	83	68	139	87	110	70	103	106	104	128	76	92	78	51	46	60	65	62	77	63
			140	122	134	153	112	98	126	125	126	95	139	124	136	94	112	88	95	111	74	77	85	82	68
94	112	96	91	97	101	96	89	139	98	92	100	95	85	96	86	93	100	92	93	66	67	76	78	89	81
			90	96	97	93	88	95	108	99	137	98	84	99	96	94	99	97	84	104	68	80	77	92	82
84	111	87	105	100	108	88	71	98	93	103	84	97	113	108	95	86	95	80	55	54	58	71	70	66	60
			110	99	116	106	78	62	93	104	81	88	129	119	117	102	104	85	67	55	67	85	76	74	64
90	74	107	114	107	125	110	95	93	106	117	104	95	116	108	135	106	99	97	98	100	90	97	102	105	102
			128	123	126	135	124	116	108	116	106	116	122	111	127	119	100	90	109	113	103	105	106	105	102
94	120	90	107	101	120	102	75	99	93	108	82	93	108	108	102	86	92	76	58	52	51	61	63	66	60
			115	106	125	116	76	94	89	106	76	83	124	122	110	101	109	77	64	47	64	75	70	68	53
99	122	107	127	117	146	116	78	90	112	131	100	87	145	129	162	104	103	97	59	59	82	84	85	67	69
			123	116	143	110	96	137	103	129	86	114	163	129	144	103	93	81	64	66	84	92	95	64	72
98	97	94	110	111	123	103	93	76	117	128	113	87	117	110	126	115	108	104	108	98	92	89	90	93	78
			109	108	117	105	89	106	113	122	109	122	125	118	116	123	101	84	85	89	105	112	116	73	72
58	73	63	163	137	120	255	99		125	122	132	89		158		135	104	104	78	49	124	99	100	88	68
			136	121	114	171	103		103	115	96	87		126		149	103	91	75	57	125	97	91	76	69
93	100	87	119	109	118	136	83	100	107	109	110	98	137	125	121	114	97	89	94	72	82	76	80	90	76
			114	109	112	126	98	113	88	105	78	100	130	114	112	113	86	78	64	61	80	79	79	64	67
90	78	98	117	111	93	158	136	107	103	90	121	113	91	100	88	153	116	108	156	118	137	106	105	157	129
			126	109	93	182	114	79	98	98	100	99	100	105	98	115	114	121	122	124	131	115	126	126	132
99	89	100	137	128	131	152	109	91	128	128	86	116	152	136	125	147	127	118	122	99	161	105	107	133	103
			122	119	126	126	130	122	114	126	107	115	153	128	131	150	107	105	82	87	163	108	113	87	99
98	88	108	129	124	122	143	97	117	110	113	112	100	126	124	113	140	119	110	82	84	122	113	108	101	87
			116	106	108	131	99	102	113	106	125	112	115	115	117	144	97	98	54	50	130	105	98	65	62
117	132	127	116	116	136	105	95	92	115	127	104	97	115	115	159	103	107	108	86	96	128	106	115	98	103
			120	111	127	121	97	131	116	114	117	122	147	118	112	102	99	99	72	70	133	104	113	91	104
97	116	104	101	101	95	118	120	176	109	97	124	145	117	102	98	95	106	100	93	106	110	97	96	95	99
			102	104	90	127	114	90	119	104	140	154	98	111	97	134	94	99	61	98	136	100	105	68	71
117	121	101	85	97	99	80	83	71	99	99	100	92	100	95	90	88	98	110	133	158	109	104	104	119	150
			93	95	103	89	92	71	81	97	70	96	87	91	99	92	96	116	120	157	94	97	105	103	160
77	63	62	68	77	71	71	51	40	93	91	94	56	103	95	141	90	73	90	51	84	83	87	94	57	57
			61	67	59	69	51						77	73	83	110						81	103		
42	65	47	93	88	89	101	33	64	74	82	67	285	103	107	72	105		93	51						40
			38	61	93	17	18	36	46	75	28	129		71	93	48		63							17
58	71	57	78	86	54	122	128	209	88	79	97	155	72	98	68	109	120	98	117	89	88	108	100	90	89
			84	78	68	108	74		75	72	157	41	82	99	64	132	121	109			120	123	127		
67	67		110	100	110	113	50	50	100	109	92	56	112	108	108	108	73	91	89		71	91	81	68	
			88	89	110	73	58	96				36	66	92	91	77	93	92				80	79		
107	112	101	93	92	105	84	94	90	87	108	72	115	92	92	79	68	80	87	87	79	87	95	93	75	84
			97	96	90	101	97	121	99	104	96	104	108	98	64	76	69	73			86	96	90		
			68	78	65	74	146	109						74		95	95	96			94	105	98		
			75	94	67	84	143	97						83		83	90				100	98	101		
133	85	175	100	102	122	89	103	126	98	110	91	115	96	89	102	88	90	99	114	108	116	111	112	115	113
			111	108	115	116	132	194	104	110	102	171	116	99	99	94	101	105	101	101	128	113	110	120	127

1	2	3	4	5	6	7	8	9	10
142		*Prunus serotina*	Cherry, black	Pennsylvania	Green	0.534	0.471		55
					Air-dry			0.506	12
143		*Pyrus malus*	Applewood or wild apple	Virginia	Green	0.745	0.606		47
					Air-dry			0.668	12
144	*Salicaceae*	*Populus balsamifera*	Poplar, balsam	Vermont	Green	0.331	0.301		121
					Air-dry			0.316	12
145		*Populus deltoides*	Cottonwood, eastern	Missouri	Green	0.433	0.372		111
					Air-dry			0.408	12
146		*Populus grandidentata*	Aspen, large tooth	Wisconsin, Vermont	Green	0.412	0.348		99
					Air-dry			0.386	12
147		*Populus tremuloides*	Aspen	Wisconsin, New Mexico	Green	0.401	0.351		94
					Air-dry			0.380	12
148		*Populus trichocarpa*	Cottonwood, black	Washington	Green	0.368	0.315		132
					Air-dry			0.348	12
149		*Salix lasiandra*	Willow, western black	Oregon	Green	0.473	0.394		105
					Air-dry			0.441	12
150		*Salix nigra*	Willow, black	Wisconsin, Missouri	Green	0.408	0.338		139
					Air-dry			0.372	12
151	*Sapindaceae*	*Exothea paniculata*	Inkwood	Florida	Green	0.917	0.731		56
					Air-dry			0.800	12
152	*Sapotaceae*	*Dipholis salicifolia*	Bustic	Florida	Green		0.861		44
					Air-dry			0.885	12
153		*Sideroxylon mastichodendron*	Mastic	Florida	Green	1.034	0.886		39
					Air-dry			0.932	12
154	*Simaroubaceae*	*Simarouba glauca*	Paradise-tree	Florida	Green	0.359	0.332		81
					Air-dry			0.345	12
155	*Styracaceae*	*Mohrodendron carolinum*	Silverbell-tree	Tennessee	Green	0.475	0.418		70
					Air-dry			0.453	12
156	*Taxaceae*	*Taxus brevifolia*	Yew, Pacific	Washington	Green	0.673	0.601		44
					Air-dry			0.626	12
157	*Tiliaceae*	*Tilia glabra*	Basswood	Wisconsin, Pennsylvania	Green	0.398	0.325		103
					Air-dry			0.368	12
158	*Ulmaceae*	*Celtis laevigata*	Sugarberry	Missouri	Green	0.545	0.473		62
					Air-dry			0.515	12
159		*Celtis occidentalis*	Hackberry	Indiana, Wisconsin	Green	0.558	0.486		65
					Air-dry			0.531	12
160		*Ulmus americana*	Elm, American	Wisconsin, Pennsylvania, New Hampshire	Green	0.554	0.458		89
					Air-dry			0.507	12
161		*Ulmus fulva*	Elm, slippery	Indiana, Wisconsin	Green	0.568	0.485		85
					Air-dry			0.528	12
162		*Ulmus racemosa*	Elm, rock	Wisconsin	Green	0.658	0.574		49
					Air-dry			0.634	12
163	*Verbenaceae*	*Avicennia nitida*	Blackwood	Florida	Green	0.963	0.830		42
					Air-dry			0.830	12

TABLE 1A.—STRENGTH AND RELATED PROPERTIES OF

I. Equations expressing strength properties

1	2	3	4	5	6	7	8	9	10	11	12	13	14
													$F = 12.08D_a{}^{1.25}$

II. Values as determined by tests—strength values

1	2	3	4	5	6	7	8	9	10	11	12	13	14
170	*Dipterocarpaceae*	*Dipterocarpus grandiflorus*	Apitong	P. I.	*d*	0.687							97
171		*Pentacme contorta*	White Lauan	P. I.	*d*	0.485							112
172		*Shorea negrosensis*	Red Lauan	P. I.	*d*	0.523							89
173		*Shorea polysperma*	Tangile	P. I.	*d*	0.538							102
174	*Sterculiaceae*	*Tarrietia javanica*	Lumbayau	P. I.	*d*	0.571							95

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
92	86	92	104	116	117	101	135	136	109	106	117	108	118	112	112	81	112	115	120	130	110	111	101	122	130
			128	114	105	166	115	77	103	110	95	101	142	118	110	87	115	132	107	105	146	110	128	125	96
109	102	102	66	78	73	65	106	78	60	65	60	69	62	73	98	88	120	120	117	122	86	100	97	112	108
			66	82	68	76	146	95	84	66	91	91	54	75	115	71	92	84	81		112	117	112	102	
100			93	102	112	80	97	91	116	108	126	129	75	85	103	78	89	95	96	100	105	111	110	132	129
			98	111	115	94	132	104	104	115	100	113	105	99	104	111	103	113	162	150	112	102	123	160	170
142	115	151	96	102	115	89	116	124	103	117	96	103	90	90	118	75	87	96	149	139	95	93	94	133	139
			108	104	121	103	110	187	71	99	57	99	99	102	101	80	82	94	147	184	93	89	86	125	149
127	103	139	106	114	136	88	100	105	116	123	113	102	104	106	124	91	103	112	133	120	115	115	118	136	131
			110	116	131	97	126	119	120	119	127	126	116	114	123	104	105	113	132	120	112	96	94	117	126
124	109	116	114	107	103	135	112	100	107	100	123	123	89	90	106	79	95	96	101	84	79	93	93	99	88
			115	112	112	122	130	122	97	108	93	122	98	94	114	90	89	90	113	68	97	85	80	116	123
148	124	165	118	116	144	102	106	122	121	129	116	132	107	102	124	92	97	103	129	138	100	100	100	133	156
			120	123	129	113	131	127	118	121	115	145	120	106	113	89	119	113	115	144	124	102	101	147	150
131	81	141	97	102	110	97	154	155	103	115	96	147	87	88	117	91	104	113	112	111	107	122	117	121	111
			95	93	107	89	119	168	100	98	104	137	90	88	112	89	99	102	130	136	115	106	107	119	127
153	81	142	67	83	70	75	204	156	83	77	95	208	54	66	65	82	92	98	180	183	107	118	123	163	181
			82	84	70	116	137	103	86	77	106	114	63	78	66	99	112	115	162	157	108	111	110	148	193
97	100	91	104	90	89	124	78	116	95	88	102	76	84	91	93	108	101	102		71	72	85	86	82	63
			71	77	85	59	47	48				45	62	86	78	91	85	98			108	100	96		57
			68	84	91	51	63						83	92	90	79									
													58	89	100										
50	76	52	80	68	76	88	28	26	88	82	98	56	101	98	70	118	71	81	60	67	59	72	63	46	47
			43	43	68	28	21	11	49	72	34	28	45	61	64	71	36	61	34	42	51	46	54	30	38
98	73	96	74	78	89	85	35	21	90	87	95	44	71	81	103	106	121	100	150	123	112	82	89	130	101
			88	78	88	79	62	43	66	93	48	47	75	72	84	96	72	71	140	129	139	109	101		
113	100	112	102	109	118	94	113	103	113	113	114	109	95	100	102	102	110	108	126	130	106	99	97	133	140
			94	90	104	90	84	88	117	109	124	102	88	95	110	89	97	98	114	110	111	93	97	118	142
61	73	55	120	108	69	218	138	174	104	88	124	81	106	115	54	109	123	118	61	60	113	112	99	63	54
			101	107	78	133	131	101	70	72	69	74	81	108	59	135	120	132		47	123	139	108	43	42
184	220	176	107	114	134	93	105	95	105	111	102	104	100	101	136	89	96	100	122	131	96	92	89	118	121
			125	118	142	120	130	109	110	120	107	98	111	108	145	96	112	118	94	147	104	104	105	139	150
101	116	95	79	94	73	98	125	138	88	86	91	107	78	88	64	105	105	105	158	130	121	119	113	145	140
			88	90	80	113	110	128	86	79	95	120	90	93	69	124	90	92	138		122	120	109	113	119
107	109	111	70	90	83	70	144	150	81	78	86	148	80	81	66	83	103	104	135	123	102	104	102	129	120
			79	95	81	83	120	141	98	83	116	137	79	86	64	100	107	112	89	107	97	96	101	91	101
120	100	127	101	108	103	108	130	130	95	102	91	130	78	94	102	85	103	107	145	132	105	105	106	142	126
			107	109	95	130	132	154	103	90	121	134	93	90	83	88	113	108	137	115	109	101	105	122	109
111	111	113	97	112	108	99	152	182	95	96	94	145	111	101	93	87	113	102	151	118	102	99	98	146	128
			104	114	101	115	160	211	111	98	126	147	101	101	94	93	115	110	111	73	99	95	97	109	96
93	92	86	89	107	88	93	146	136	98	100	94	124	92	97	75	88	111	106	212	128	92	93	95	161	112
			85	103	87	91	130	154	95	92	99	131	86	93	94	94	103	106	90	95	89	100	97	77	99
71	83	71	68	80	79	63	48	55	84	85	84	50	81	88	74	95	72	64	58	38	64	74	78	36	33
			65	80	89	49	76	135						82		77									

Certain Woods of the Philippine Islands

of air-dry wood in terms of density

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
$F = 20.90D_a^{1.25}$	$F = 2750D_a^{1.00}$	$F = 0.00416D_a^{2}$							$F = 7.38D_o^{1.25}$	$F = 8.37D_o^{1.00}$		$F = 2.71D_o^{2.25}$	$F = 2.17D_o^{1.33}$	$F = 2.17D_o^{1.33}$			$F = 1466D_o^{2.25}$	$F = 1365D_o^{2.25}$	$F = 1365D_o^{2.25}$		

expressed in percentage of equation values

95	**102**	**98**							103	109		84	99	99			87	89	89		
112	**109**	**107**	For other Philippine woods, *see* Bulletins						116	102		113	110	110			135	135	135		
85	**85**	**90**	Nos. 4 and 14, Bureau of Forestry, Philip-						106	99		92	108	108			95	96	96		
107	**103**	**114**	pine Islands 1907 and 1916.						96	96		109	98	98			108	106	106		
101	**103**	**108**							92	84		108	95	95			104	111	111		

WOODS NATIVE TO

PHILIP

STRENGTH AND

For Canada, *v.* p. 4; for

Index No.	Botanical name: Family	Botanical name: Genus and species	Local name	Place of growth	Seasoning condition	Bulk density: Green	Bulk density: Air-dry
						g/cm³	
1	2	3	4	5	6	7	8
200	*Aceraceae*	*Acer pseudo-platanus*, Linn.	Sycamore	British Isles	Air-dry		
201	*Anacardiaceae*	*Campnosperma* sp.	Terentang	Fed. Malay States	Air-dry		0.348
202		*Euroschinus falcatus*, Hook., f.	Port Macquarie beech	Australia			0.433‡
203		*Harpephyllum caffrum*, Bernh.	Kaffir plum, Zuurbesje, um-Gwenya, Mategibe	S. Africa			0.691‡
204		*Mangifera indica*, Linn.	Am, Mango, Thayet	India			0.674‡
205		*Melanorrhoea* ? sp.	Rengas	Fed. Malay States	Green	0.697	
206		*Protorhus longifolia*, Engl.	Red Cape beech, Rode Melkhout, um-Komiso	S. Africa			0.680‡
207		*Rhus lucida*, Linn.	Taaibosch, in-Tlokoebomve, Manzi-mane	S. Africa			1.120‡
208	*Anonaceae*	*Alphonsea ventricosa*, H., f. and Th.	Chooi	India			0.785‡
209	*Apocynaceae*	*Dyera costulata*, Hook., f.	Jelutong	Fed. Malay States	Air-dry		0.369‡
210		*Rauwolfia natalensis*, Sond.	Quinine tree, um-Hlambamasi	S. Africa			0.530‡
211	*Aquifoliaceae*	*Ilex capensis*, Sond. and Harv.	Water tree, Wittehout, um-Duma	S. Africa			0.610‡
212	*Araliaceae*	*Cussonia* sp.	Cabbage wood, um-Senge	S. Africa			0.460‡
213		*Panax pinnatum*, A. Rich.	Mutati	E. Africa	Air-dry		0.360
214	*Betulaceae*	*Betula* spp.	Birch	British Isles	Air-dry		
215	*Bombaceae*	*Bombax insigne*, Wall.	Didu, Saitu, Semul	India			0.497‡
216		*Coelostegia griffithii*, Benth.	Punggai	Fed. Malay States	Air-dry		0.537
217		*Cullenia excelsa*, Wight.	Karayani, Kabodda, Wild Durian	India	Green Oven-dry	0.492	
218	*Boraginaceae*	*Cordia platythyrsa*, Baker.	Pooli	W. Africa			0.396‡
219	*Burseraceae*	*Canarium australianum*, F. Muell.	Turpentine pine	Australia			0.644‡
220		*Canarium bengalense*, Roxb.	Neribi	India			0.625‡
221		*Canarium mauritianum*, Bl.	Colophane	Mauritius			0.813‡
222		*Santiriopsis klaineana*, Pierre	Odonomokuku, incense tree	W. Africa			0.702‡
223	*Casuarinaceae*	*Casuarina cunninghamii*, Miq.	River oak	New South Wales, Queensland			0.769‡
224		*Casuarina decussata*, Benth.	Karri Shea-oak	W. Australia	Green	0.702	
225		*Casuarina equisetifolia*, Forst.	Beefwood, Ru, Chouk, Kabwi	India, Fed. Malay States, Queensland	Green	0.785	
226		*Casuarina fraseriana*, Miq.	Shea oak	W. Australia	Green	0.723	0.744
227		*Casuarina glauca*, Sieb.	Swamp oak	Australia	Green	0.852	0.930
228		*Casuarina torulosa*, Ait.	Forest oak	Australia			1.028‡
229	*Celastraceae*	*Cathastrum capense*, Turcz.	Hard pear, coffee pear, um-Ngqangqa	S. Africa			0.900‡
230		*Elaeodendron croceum*, DC.	Saffraanhout, saffronwood, um-Bom-vana	S. Africa			0.894‡
231		*Elaeodendron velutinum*, Harv.	um-Nqai, um-Ngayi	S. Africa			0.960‡
232		*Pleurostylia wightii*, Wight and Arn.	Panaka, Pairi, Chiru-piyari	Ceylon			0.879‡
233		*Pterocelastrus rostratus*, Walp.	White pearwood	S. Africa			0.686‡
234		*Pterocelastrus variabilis*, Sond.	Candlewood, Kersehout, Itwyina	S. Africa			1.063‡
235	*Combretaceae*	*Anogeissus acuminata*, Wall.	Yon, Chakwa, Panchi	India	Green	0.739	
236		*Anogeissus latifolia*, Wall.	Bakli, Dhaura	India	Green	0.793	
237		*Combretum kraussii*, Hochst.	Bush willow, Rodeblad, um-Dubu-weklati	S. Africa			0.850‡
238		*Terminalia bialata*, Wall.	Indian silver greywood, white Chug-lam, Lein, Chugalam	India			0.769‡
239		*Terminalia myriocarpa*, Huerck. and Muell. Arg.	Hollock, Panisaj, Sungloch, Shila	India			0.834‡
240		*Terminalia paniculata*, Roth	Kindal, Kirijul	India			0.898‡
241		*Terminalia procera*, Roxb.	Indian almond tree, Badam, Taree	India			0.593‡

* Tension parallel to grain.
‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

THE BRITISH EMPIRE

Harris

Related Properties

Tropical America, *v.* p. 39

Bulk density: Oven-dry	Moisture content	Static bending: Fiber stress at elastic limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work to elastic limit	Static bending: Work to maximum load	Impact bending 22.68 kg hammer: Fiber stress at elastic limit	Impact bending: Modulus of elasticity	Impact bending: Work to elastic limit	Impact bending: Height of drop causing complete failure	Compression parallel to grain: Fiber stress at elastic limit	Compression parallel to grain: Maximum crushing strength	Compression parallel to grain: Modulus of elasticity	Compression perpendicular to grain, fiber stress at elastic limit	Shear: Radial	Shear: Tangential	Tension perpendicular to grain: Radial	Tension perpendicular to grain: Tangential	Hardness: End	Hardness: Radial	Hardness: Tangential	Lit.
g/cm³	% oven-dry	kg/mm²	kg/mm²	kg/mm²	kg-cm/cm³	kg-cm/cm³	kg/mm²	kg/mm²	kg-cm/cm³	cm	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg	kg	kg	
9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0.570		2.23	7.03	872								3.89										(5)
	16	2.25	4.18	788																		(21)
			3.54	881																		(61)
		4.57	8.40	1023	0.115							4.82										(12, 49)
			6.96	1037								6.19										(31, 43)
	45	4.50	9.61	1476																		(21)
		3.16	6.40	1085	0.054							4.41										(12)
		6.79	11.21	1253	0.197							9.78										(12)
			10.20	1234								5.79			1.083							(10, 43)
	17	2.60	4.38	717																		(21)
		2.67	4.91	726	0.054							4.54										(12)
		2.17	5.11	749	0.036							4.13										(12)
		2.34	2.86	548	0.049							2.67										(12)
	11		3.38									2.25			0.387							(22)
0.53–0.786		4.75	9.78	1470								6.62										(5)
			4.61	743								2.84			0.650							(10, 43)
	19	4.75	8.73	1476																		(21)
	55	3.93	5.89	1002	0.089		8.51	1107	0.375	69	2.18	2.72	1173	0.475	0.520	0.573	0.316	0.418	333	306	284	(38)
0.554	8	5.73	9.34	1285	0.143		14.02	1747	0.612	74	3.76	5.28	1306	0.692	0.654	0.534	0.355	0.612	465	415	488	(38)
		5.03	7.54	813	0.176							4.22			0.783							(14)
			6.14	747																		(24)
			3.92	407								3.95			1.026							(10, 43)
		5.66	10.90	1272								5.69			0.988							(63)
		2.77	4.25	812								2.25			0.494							(57)
			10.13	1178																		(61)
	46	3.54	6.34	661								2.81			0.752		8.62*					(20)
	20	5.62	11.02	1589								6.68			1.58							(10, 21, 37)
	33	7.80	8.43	953											1.041		6.33*					(20)
	43	11.46	14.52	1668											0.816		11.95*					(20)
			11.38	1654								6.11	1432		1.047		11.59*					(2, 58, 59)
		3.52	6.41	761	0.091							5.54										(12)
		5.55	9.93	986	0.175							4.98			0.916							(55)
		5.16	10.82	1375	0.116							7.24										(12)
		5.32	9.11	1037	0.152							4.36			0.524							(54)
		3.74	10.93	999	0.078							4.77										(48)
		3.61	7.96	921	0.080							4.87			1.039							(55)
	35	5.63	9.24	1346	0.134		14.10	1950	0.572	112	3.08	4.62	1377	0.931	0.910	1.300	0.499	0.689	823	757	714	(41)
	35	4.47	8.51	1138	0.103		12.73	1467	0.613	144	2.16	3.83	1199	0.967	0.997	1.111	0.447	0.607	845	812	810	(31, 34, 41, 42)
		3.82	7.96	1038	0.084							5.13										(12)
			11.52	1477								5.88			1.43							(10, 43)
			11.60									3.84			0.755							(9)
			7.43									4.62										(9)
			10.18	1098								6.52			1.032							(10, 43)

1	2	3	4	5	6	7	8
242		*Terminalia superba*, Engl. and Diels.	Afara, Afram	W. Africa	Air-dry		0.440
243		*Terminalia tomentosa*, W. and A.	Indian laurel wood, Taukkyan, Sain	India	Green	0.707	
					Air-dry		0.752
					Oven-dry		
244	*Compositae*	*Brachylaena discolor*, DC.	um-Pahla, Vaalbosch, Mapata	S. Africa		0.763	
							0.816
245		*Brachylaena hutchinsii*, Hutch.	Muhugu	E. Africa	Green	0.812	
					Air-dry		0.849
246	*Coniferae* (or *pinaceae*)	*Abies pectinata*, DC.	European silver fir	British Isles†	Air-dry		
247		*Abies pindrow*, Spach.	W. Himalayan silver fir, Paludár, Bádar	India	Air-dry		0.385
248		*Agathis alba*	Damar Minyak	Fed. Malay States	Air-dry		0.497
249		*Agathis australis*, Steud.	Kauri pine	New Zealand	Air-dry		0.438
250		*Agathis robusta*, F. M. Bailey	Queensland kauri, Dundathu pine	Queensland			0.433‡
251		*Araucaria bidwillii*, Hook.	Bunya pine	Queensland	Air-dry		0.468
252		*Araucaria cunninghamii*, Sweet.	Moreton Bay pine, hoop pine	New South Wales, S. Queensland	Air-dry		0.470
253		*Athrotaxis selaginoides*, D. Don.	King William pine	Tasmania			0.369‡
254		*Callitris arborea*, Schrad.	Clanwilliam cedar	S. Africa			0.618‡
255		*Callitris calcarata*, R. Br.	Black cypress pine	New South Wales, Queensland			0.753‡
256		*Callitris rhomboidea*, R. Br.	Illawara Mountain pine, cypress pine	India†	Green	0.516	
257		*Callitris robusta*, R. Br.	White cypress	W. Australia			0.657‡
258		*Callitris tasmanica*, R. T. B.	Oyster Bay pine	Victoria, N. S. W., Tasmania			0.673‡
259		*Cedrus deodara*, Loud.	Deodar, Himalayan cedar	India	Green	0.468	
					Air-dry		
					Oven-dry		
260		*Cryptomeria japonica*, D. Don.	Japanese cedar	India†	Green	0.329	
261		*Cupressus macrocarpa*, Hartw.	Monterey cypress	India†	Green	0.433	
262		*Cupressus torulosa*, D. Don.	Himalayan cypress	India	Green	0.419	
					Air-dry		0.431
263		*Dacrydium colensoi*, Hook.	Westland pine, silver pine	New Zealand	Air-dry		0.547
264		*Dacrydium cupressinum*, Soland.	Rimu, red pine	New Zealand	Air-dry		0.451
265		*Dacrydium franklinii*, Hook.	Huon pine	Tasmania	Air-dry		0.536‡
266		*Juniperus procera*, Hochst.	East African juniper	E. Africa	Air-dry		0.548
267		*Larix europaea*, DC.	Larch	British Isles†			
268		*Libocedrus doniana*, Endl.	Kawaka, Wawaku	New Zealand			0.637‡
269		*Phyllocladus rhomboidalis*, A. Rich.	Celery-top pine	Tasmania			0.609‡
270		*Picea excelsa*, Link.	Norway spruce	British Isles†	Air-dry		
271		*Picea morinda*, Link.	W. Himalayan spruce, Rai	India			
				white wood	Air-dry		0.402
				red wood	Air-dry		0.436
272		*Pinus excelsa*, Wall.	Bhotan pine, blue pine, Kail, Piuni	India	Air-dry		0.405
273		*Pinus longifolia*, Roxb.	Long-needled pine, Chir	India	Green	0.541	
					Air-dry		0.505
274		*Pinus pinaster*, Soland.	Cluster pine, maritime pine	British Isles†	Air-dry		
275		*Pinus pinea*, Linn.	Stone pine	S. Africa†			0.565‡
276		*Pinus strobus*, Linn.	Weymouth pine, white pine	British Isles†	Air-dry		
277		*Pinus sylvestris*, Linn.	Dantsic fir, Scots pine	British Isles			
				heavy timber	Air-dry		
				light timber	Air-dry		
278		*Podocarpus dacrydioides*, A. Rich.	Kahikatea, white pine	New Zealand			0.436‡
279		*Podocarpus elata*, R. Br.	Brown pine	New South Wales, S. Queensland			0.817‡
280		*Podocarpus elongata*, L'Her	Outeniqua or bastard yellowwood, Geelhout, um-Koba	S. Africa		0.450	0.481
281		*Podocarpus ferrugineus*, Don.	Miro, black pine	New Zealand			0.658‡
282		*Podocarpus gracilior*, Pilg.	Musengera, Podo	E. Africa	Air-dry		0.513
283		*Podocarpus milanjianus*, Rendle	Podo	E. Africa	Air-dry		0.574
284		*Podocarpus neriifolia*, Don.	Welimadá, Thitmin	India			0.673‡
285		*Podocarpus spicata*, R. Br.	Matai, black pine	New Zealand	Air-dry		0.715
286		*Podocarpus thunbergii*, Hook. var. *falcata*, Sim.	Upright or real yellow wood, um-Sunti	S. Africa		0.597	0.626
287		*Podocarpus totara*, Don.	Totara	New Zealand	Green	0.407	
288		*Pseudotsuga douglasii*, Carr.	Douglas fir	British Isles†	Air-dry		
289		*Sequoia sempervirens*, Endl.	Redwood	Australia†			0.465‡
290	*Cornaceae*	*Curtisia faginea*, Ait.	Assagai, um-Gxina	S. Africa			0.940‡
291	*Cunoniaceae*	*Ackama muelleri*, Benth.	Corkwood	Australia			0.641‡
292		*Ceratopetalum apetalum*, D. Don.	Coachwood	Australia			0.608‡
						0.657	
293		*Cunonia capensis*, Linn.	Red alder, Rode Els, um-Nqwaskube	S. Africa			0.721
						0.527	
294		*Platylophus trifoliatus*, Don.	White alder, Witte Els	S. Africa			0.575

* Tension parallel to grain. † Not a native of this country.
‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	10	4.43	5.60	894	0.120	0.222					3.08	3.93	852	0.772	0.816	1.073						(15)
	54	4.85	7.94	1168	0.114		12.46	1615	0.552	99	2.74	3.93	1395	0.823	0.752	0.974	0.369	0.443	658	699	667	(9, 31, 38)
	13	6.50	10.81	1340	0.179		18.11	2442	0.745	122	3.42	5.82	1575	1.21	1.13	1.195	0.608	0.632	1000	930	974	
0.772	9	8.51	12.92	1538	0.264		16.70	2230	0.707	127	3.60	6.77	1715	1.32	1.146	1.20	0.780	0.871	1162	960	946	
	70	5.04	11.10	1292	0.108							8.29										(8, 12)
0.840	10																					
	28		4.22									4.99			0.415							(22)
	13		4.78									6.82			0.661							(23)
0.37-0.52		3.66	6.22	1224								4.24										(5)
	16	3.86	6.02	1070	0.079		7.77	1280	0.266	48	2.82	3.30	1682	0.323	0.537	0.496	0.179	0.169	284	184	204	(38)
	18	4.64	8.12	1343																		(21)
	15	4.85	6.60	937	0.159							4.29					12.73*					(1, 3, 4, 19, 28, 51)
			4.96	652																		(61)
	12		9.79									5.50										(6)
	15		6.32	1440								5.27	914		1.05		10.15*					(6, 9, 58, 59)
			3.95	581																		(61)
		3.32	5.81	617	0.099							3.87			0.356							(55, 56)
			2.85	844																		(61)
	31	3.39	4.60	648	0.103		7.27	851	0.358	58	1.89	2.75	99	0.703	0.721	0.671	0.126	0.369	481	386	377	(38)
			6.32	749																		(61)
			6.07	1252																		(61)
	45	3.62	6.09	948	0.079		8.51	1009	0.398	51	2.13	3.12	993	0.467	0.569	0.714	0.165	0.249	329	252	265	(31, 38)
		4.61	7.41	1022	0.171						3.05	4.31	1067	0.618	0.749	0.861	0.249	0.225	447	304	340	
		7.17	9.25	1191	0.238						4.58	6.28	1440	0.917	0.632	0.544	0.179	0.246	540	390	406	
	24	2.12	4.01	495	0.052		5.26	618	0.251	36	0.77	1.60	457	0.306	0.531	0.517	0.186	0.260	163	170	147	(38)
	40	2.52	4.35	647	0.057		7.28	886	0.348	43	1.17	2.27	668	0.429	0.534	0.696	0.151	0.295	340	265	288	(38)
	35	2.57	4.13	579	0.065		6.29	811	0.276	53	1.89	2.22	784	0.467	0.548	0.668	0.137	0.341	334	231	227	(38)
	10	4.70	6.43	746	0.170		9.34	1193	0.413	56	2.09	3.34	785	0.685	0.731	0.872	0.211	0.559	438	263	293	(38)
	17	3.82	6.85	1006								5.48					12.87*					(4, 28)
	14	4.86	7.85	1273								4.33					10.07*					(1, 3, 4, 19, 28)
		3.14	6.96	467	0.111																	(3)
	15		3.38									4.85			0.309							(22)
0.45-0.75		4.80	11.25	1700								6.43										(5)
		3.80	6.07	664	0.141																	(3)
			7.33	1177																		(61)
0.30-0.52		4.42	7.42	1371								4.70										(5, 61)
	15	3.81	6.17	1020	0.081		8.26	1331	0.285	53	2.14	3.15	1447	0.469	0.684	0.710	0.274	0.249	326	202	220	(38, 39)
	14	4.32	7.21	1114	0.096		9.01	1550	0.297	66	2.21	3.24	1512	0.477	0.885	0.805	0.278	0.310	336	252	268	(38, 39)
	14	3.23	4.77	693								4.40			0.802							(31, 38)
	78	3.25	5.53	1047	0.057		8.13	1205	0.309	61	2.13	2.86	1136	0.531	0.601	0.618	0.222	0.228	261	252	318	(31, 38)
	15	4.02	6.90	1175	0.077		9.32	1662	0.301	61	2.18	3.57	1575	0.485	0.752	0.773	0.214	0.172	377	295	322	(31, 38)
0.41-0.59		2.81	7.17	971								4.94			0.771							(5, 55, 56)
		2.70	7.35	669	0.061							3.49			0.579							(55, 56)
0.42 -0.55		4.71	10.23	1202								6.25										(5)
0.51 -0.76		5.22	10.97	1821								7.10					5.62*					(5, 25)
0.375-0.50		3.68	8.30	1329								5.23										(5, 25)
		2.19	5.42	889								3.19					9.46*					(3, 4, 19, 28)
			5.83	896																		(61)
	110	4.08	6.08	837	0.113							3.76			0.427							(8, 12, 55)
0.500	10																					
		5.22	9.62	759	0.202																	(3)
	13		6.12									4.08			0.372							(22)
	15		5.91									4.01			0.507							(22)
			9.29	1110								5.62			1.097							(10, 43)
	12	6.73	9.98	1119	0.235							3.52					>4.92*					(3, 4, 13, 28)
	100	4.76	7.13	854	0.149							4.24			0.413							(8, 12, 55)
0.650	10																					
	45	3.12	5.09	831								3.03			0.703		10.20*					(1, 3, 4, 19, 28)
0.45-0.55		4.38	7.47	1300								5.17										(5)
			6.52	1120																		(61)
		7.47	11.07	1486	0.212							6.04			0.939							(12, 55)
			10.34	1550																		(61)
			7.42	1109								4.66	941		1.365		9.03*					(59)
	60																					
	10	5.35	8.50	1238	0.129							4.71			0.771							(8, 55)
0.750	0																					
	130																					
	10	3.50	4.91	527	0.130							4.20			0.458							(8, 55)
0.605	0																					

1	2	3	4	5	6	7	8
295		*Weinmannia lachnocarpa*, F. Muell.	Mararie	New South Wales, Queensland			0.802‡
296		*Weinmannia racemosa*, Linn., f.	Kamahi	New Zealand	Green	0.512	
296.5	*Dilleniaceae*	*Dillenia indica*, Linn.	Ottengah, Thabyu, Chalta	India			0.705‡
297	*Dipterocarpaceae*	*Anisoptera* sp.	Sanai	Fed. Malay States	Air-dry		0.489
298		*Balanocarpus maximus*, King.	Chengal, Penak	Fed. Malay States	Air-dry		0.785
299		*Balanocarpus penangianus*, King.	Damar Hitan	Fed. Malay States	Green	0.589	
300		*Balanocarpus* sp.	Chengal, Penak	Fed. Malay States	Air-dry		0.609
301		*Dipterocarpus alatus*, Roxb.	Kanyin	India	Green	0.574	
					Air-dry		0.604
					Oven-dry		
302		*Dipterocarpus pilosus*, Roxb.	Hollong	India			0.689‡
303		*Dipterocarpus* sp.	Keruing, Kruin	Fed. Malay States, Borneo	Air-dry		0.665
304		*Dipterocarpus tuberculatus*, Roxb.	In, Sooahn	India	Green	0.726	
					Air-dry		
305		*Dipterocarpus turbinatus*, Gaertn. F.	Gurjan	India	Green	0.655	
					Air-dry		
					Oven-dry		
306		*Dryobalanops aromatica*, Gaertn.	Kapur, Camphor-wood	Fed. Malay States, Borneo	Air-dry		0.689
307		*Dryobalanops* sp.	Keladan	Fed. Malay States	Green	0.601	
308		*Hopea odorata*, Roxb.	Thingan, Rinda	India			0.785‡
309		*Hopea* sp.	Merawan	Fed. Malay States	Green	0.608	
310		*Shorea acuminata*, Dyer	Meranti Rambai Daun	Fed. Malay States	Green	0.447	
311		*Shorea assamica*, Dyer	Makai	India			0.577‡
312		*Shorea barbata*, Brandis	Rasak	Fed. Malay States	Air-dry		0.817
313		*Shorea contorta*, Vidal	White Lauan	Australia			0.513‡
314		*Shorea curtisii*, Dyer	Seriah	Fed. Malay States	Air-dry		0.513
315		*Shorea*, *Hopea* and *Isoptera* spp.	Salangan batu, Yacal	Borneo	Green	0.689	
316		*Shorea leprosula*, Miq.	Meranti Bunga	Fed. Malay States	Air-dry		0.483
317		*Shorea macroptera*, Dyer	Melantai	Fed. Malay States	Green	0.454	
318		*Shorea obtusa*, Wall.	Thitya	India			0.961‡
319		*Shorea parvifolia*, Dyer	Meranti Sarang Punai	Fed. Malay States	Air-dry		0.436
320		*Shorea robusta*, Gaertn., f.	Sál, Sákher	India	Green	0.714	
					Green	0.772	
321		*Shorea sericea*, Dyer	Meranti Kepong	Fed. Malay States	Air-dry		0.374
322		*Shorea* sp.	Damar Laut Daun Besar	Fed. Malay States	Air-dry		0.837
			Damar Laut Daun Kechil	Fed. Malay States	Air-dry		0.920
			Merani Kait Kait	Fed. Malay States	Green	0.513	
			Seraya Batu	Fed. Malay States	Air-dry		0.777
			White Seriah, cedar	Borneo			0.481–0.641‡
323		*Vatica affinis*, Thw.	Mandora	Ceylon			0.957‡
324	*Ebenaceae*	*Diospyros kurzii*, Hiern.	Andaman marble-wood, Thitkya, Pecha-da	India			0.978‡
325		*Diospyros melanida*, Poir.	Ebène marbre	Mauritius			0.768‡
326		*Diospyros pentamera*, Woods and F. Muell.	Grey plum	New South Wales, Queensland			0.705‡
327		*Diospyros* sp.	Kayu Arang	Fed. Malay States	Air-dry		0.798
328		*Euclea natalensis*, A. DC.	i-Dungamuzi	S. Africa			0.890‡
329		*Royena lucida*, Linn.	Black-bark, Zwartbast, um-Tenattena	S. Africa			0.770‡
330	*Elaeocarpaceae*	*Aristotelia racemosa*, Hook., f.	Moko	New Zealand			0.593‡
331		*Elaeocarpus dentatus*, Vahl.	Hinau	New Zealand			0.562‡
332		*Elaeocarpus grandis*, F. Muell.	Blue fig	Australia			0.665‡
333		*Sloanea woollsii*, F. Muell.	Mellow Carrabeen	Australia			0.577‡
334	*Eucryphiaceae*	*Eucryphia billiardieri*, Spach.	Leatherwood	Tasmania			0.785‡
335	*Euphorbiaceae*	*Baccaurea sapida*, Muell. Arg.	Latecku, Lutio, Kanazo	India			0.673‡
336		*Beyeria viscosa*, Miq.	Pinkwood	Australia			0.704‡
337		*Bischofia javanica*, Bl.	Uriana, Tayôkthé, Aukkyu, Boa-ungsa, red cedar	India			0.721‡
338		*Bridelia micrantha*, Baill.	um-Hlahlamakwaba, Mazerie	S. Africa			0.590‡
339		*Hemicyclia australasica*, Muell. Arg.	Yellow tulip wood	Queensland, New South Wales			0.865‡
340		*Ricinodendron africanus*, Muell. Arg.	Ochwen	W. Africa			0.789‡
341	*Fagaceae*	*Castanea sativa*, Mill.	Sweet chestnut	British Isles†	Air-dry		
342		*Castanopsis hystrix*, A. DC.	Chestnut, Dalné, Hingori, Sirikishu	India			0.737‡
343		*Castanopsis* sp.	Berangan	Fed. Malay States	Green	0.569	
344		*Fagus cunninghamii*, Hook.	Tasmanian myrtle, red myrtle	Australia	Green	0.656	
345		*Fagus fusca*, Hook., f.	Red beech, black birch, Towai	New Zealand			0.577‡
346		*Fagus menziesii*, Hook., f.	Silver beech, red birch, Towai	New Zealand			0.593‡
347		*Fagus moorei*, F. Muell.	Negro head, white beech	New South Wales			0.860‡
348		*Fagus sylvatica*, Linn.	Beech	British Isles	Air-dry		
349		*Quercus lamellosa*, Sm.	Hill oak, Búk	India			0.945‡
350		*Quercus pedunculata*, Ebrh.	Oak	British Isles	Air-dry		0.744
351		*Quercus robur*, Linn.	Oak	British Isles	Air-dry		
352		*Quercus sessiliflora*, Salisb.	Oak	British Isles			0.785‡

* Tension parallel to grain. † Not a native of this country.
‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
			13.30	1892																		(61)
	71	2.68	5.38	845	0.056	0.725					2.04	2.39		0.524	0.860	0.956	0.363	0.497	406	336	365	(29)
			8.34	1036								5.17				1.014						(10, 43)
	19	3.44	6.46	1012																		(21)
	17	7.81	11.49	1723																		(21)
	24	4.28	7.76	1192																		(21)
	17	6.75	9.93	1455																		(21)
	73	3.76	6.61	1039	0.077		10.70	1482	0.443	74	1.71	3.18	1122	0.534	0.671	0.752	0.506	0.745	402	413	392	(31, 38)
	17	4.25	8.79	1333	0.077		13.04	1553	0.629	76	2.86	4.57	1207	0.618	0.885	1.044	0.432	0.594	503	447	438	
		7.81	9.61	1346	0.252						4.22	6.62	1501	0.784	0.889	0.904	0.639	0.714	680	537	501	
		11.49										4.16			0.787							(34, 43)
	17	4.29	7.41	1237								3.42										(9, 21)
	50	4.91	8.15	1233	0.110		14.13	1886	0.604	102	2.58	3.96	1422	0.858	0.840	0.946	0.415	0.671	660	644	644	(31, 38, 46)
		5.07	9.79	1381	0.105						2.49	4.77	1523	0.633	0.970	1.125	0.566	0.756	715	733	710	
	66	4.88	7.75	1420	0.095		13.12	1896	0.507	81	2.73	4.12	1597	0.668	0.622	0.742	0.520	0.622	481	463	458	(38)
		5.69	10.97	1574	0.117						2.62	5.44	1672	0.833	0.816	0.946	0.886	0.618	596	633	583	
		9.47	13.83	1775	0.288						6.68	8.75	1624	0.956	0.932	0.886	0.625	0.724	703	664	646	
	19	5.03	10.04	1680								3.89										(9, 21)
	21	3.94	8.64	1399																		(21)
			11.50	1465								5.87			1.46							(10, 30, 31, 43)
	20	5.68	10.28	1623																		(21)
	20	3.38	6.62	1005																		(21)
			8.30	1102								4.49			0.934							(10, 43)
	18	5.92	13.73	2005																		(21)
			6.25	663																		(61)
	19	3.84	7.58	1234																		(21)
	28		8.66	1425								5.22										(9, 37)
	18	3.83	6.85	1203																		(21)
	21	3.97	6.77	1244																		(21)
			15.64	1776								8.54			1.873							(9, 31, 43)
	19	3.30	5.83	1033																		(21)
	56	5.56	9.92	1373	0.128		13.44	1792	0.569	101	3.53	4.65	1432	0.984	0.914	0.972	0.480	0.678	625	679	692	(31, 36, 38, 40, 43)
	28	5.55	10.65	1350	0.136							5.76			1.307							
	17	2.85	5.28	1005																		(21)
	17	6.02	13.32	1920																		(9, 21)
	17	6.33	12.88	1860																		
	31	4.10	7.53	1417																		
	16	5.17	9.21	1167																		
			7.20									3.59										
		5.46	9.64	1316	0.107							4.12			0.436							(54)
			7.80	1270								6.30			1.49							(10, 43)
		3.78	5.55	1007								4.43			1.068							(63)
			9.75	1502																		(61)
	16	5.38	11.02	1596																		(21)
		4.69	8.98	1488	0.081							4.84										(12)
		2.86	6.57	668	0.068							4.24										(12)
		3.14	6.17	452	0.131																	(3)
		4.76	6.33	975	0.129																	(3)
			8.11	1184								5.58	1087		1.466		12.46*					(59)
			9.08	1342																		(61)
			14.10	1668																		(2)
			7.51	925								4.62			0.786							(10)
		5.06	9.86	867	0.164																	(3)
			6.02	598								4.42										(10, 43)
		3.16	5.25	976	0.060							5.05										(12)
			8.82	1237																		(2, 61)
		3.81	6.29	1046								3.78			0.687							(57)
0.44–0.60		2.90	7.70	925								5.17										(5)
			7.42	908								4.05			1.274							(10, 43)
	22	3.87	6.94	1073																		(21)
	28	4.98	6.40	1327	0.104							4.07			0.876		6.27*					(51, 61)
			8.08	1054								4.20			0.63		5.60*					(3, 13, 28)
			7.73	914								4.20			0.63		5.60*					(3, 13, 28)
			8.15	1157								5.22	1274		0.736		14.40*					(2, 13, 59)
0.61–0.75		3.69	10.34	1389								5.09					7.73*					(1, 5)
			8.94	1225								5.18			1.69							(10, 31, 43)
	12		8.30									6.05					7.38*					(20)
0.60–0.813		3.78	10.37	1533								6.22					7.03–13.35*					(1, 5, 25)
			6.85	805																		(12)

1	2	3	4	5	6	7	8
354	*Flacourtiaceae*	*Dovyalis zizyphoides*, E. Mey.	Zuurbesjes, um-Kokolo	S. Africa			0.870‡
355		*Kiggelaria africana*, Linn.	Wild peach, Spekhout, Mpataselo	S. Africa			0.650‡
356		*Scolopia ecklonii*, Arn.	Red pear, Rode Peer	S. Africa			0.840‡
357		*Scolopia zeyheri*, Arn.	Thorn pear, Wolvedoorn	S. Africa			1.000‡
358		*Trimeria alnifolia*, Harv.	Wild mulberry, Wilde Moerbe, Xalebo	S. Africa			0.790‡
359	*Guttiferae*	*Calophyllum bracteatum*, Thw.	Walukina	Ceylon			0.519‡
360		*Calophyllum calaba*, Linn.	Gurukina	Ceylon			0.705‡
361		*Calophyllum inophyllum*, Linn.	Alexandrian laurel, Tharapi, Sultana champa, Puna	India			0.673‡
362		*Calophyllum* sp.	Bintangor	Fed. Malay States	Air-dry		0.529
363		*Calophyllum spectabile*, Willd.	Dakar talada, Pantaga, Lal chuni	India			0.617‡
364		*Garcinia conrauana*, Engl.	Orugbo	W. Africa			0.716‡
365		*Kayea assamica*, King and Prain	Sia Nahor	India	Green	0.745	
366		*Mesua ferrea*, Linn.	Penaga (F. M. S.), Nageshwa, Gangaw	India	Air-dry		0.897
367	*Hamamelidaceae*	*Bucklandia populnea*, R. Br.	Pipli, Dinghah, Singliang	India			0.721‡
368		*Parrotia jacquemontiana*, Dcne.	Peshora, Shtar	India	Green	0.694	
369	*Icacinaceae*	*Apodytes dimidiata*, E. Mey.	White pear, Witte Peer, um-Dakane	S. Africa		0.636	0.670
370		*Villaresia moorei*, F. Muell.	New South Wales maple	Australia			0.689‡
371	*Lauraceae*	*Beilschmiedia obtusifolia*, Benth.	Pomatum wood, She beech	New South Wales, Queensland			0.737‡
372		*Beilschmiedia tarairi*, Benth. and H., f.	Taraire	New Zealand			0.888‡
373		*Beilschmiedia tawa*, Benth. and H., f.	Tawa	New Zealand	Green	0.533	
					Air-dry		0.555
374		*Cinnamomum oliveri*, F. M. Bailey	Black sassafras	Australia			0.513‡
375		*Cryptocarya patentinervis*, F. Muell.		New South Wales, Queensland			0.657‡
376		*Endiandra discolor*, Benth.	Murrogun	New South Wales, Queensland			0.753‡
377		*Endiandra pubens*, Meissn.		Queensland			0.721‡
378		*Eusideroxylon zwageri*, Teijsm. and Binn.	Borneo ironwood, Billian	Borneo	Green	0.960	
			Billian	Fed. Malay States	Air-dry		0.938
379		*Litsea calicaris*, Kirk.	Mangi, Mangeao, Tangeao	New Zealand			0.621‡
380		*Litsea reticulata*, Meissn.	She beech, Bally Gum	Australia			0.433‡
381		*Litsea reticulata*, Meissn. and *Litsea ferruginea*, Bl.	Bally gum	Australia	Air-dry		0.484
382		*Litsea* sp.	Medang	Fed. Malay States	Green	0.601	
383		*Litsea* ? sp.	Medang Tandok	Fed. Malay States	Air-dry		0.721
384		*Machilus odoratissima*, Ness.	Lalie, Leddil, Kaula, Seiknangyi	India			0.641‡
385		*Ocotea bullata*, E. Mey.	Black stinkwood, stinkhout	S. Africa		0.659	0.758
386		*Ocotea usambarensis*	Muzaiti, camphor	E. Africa	Green	0.547	
					Air-dry		0.558
387		*Persea semicarpifolia*	Ranai	Ceylon			1.015‡
388	*Leguminosae*	*Acacia acuminata*, Benth.	Jam wood	W. Australia	Green	0.935	
389		*Acacia arabica*, Willd.	Babul, Kikar	India			0.865‡
390		*Acacia horrida*, Willd.	Doornboom, thorn tree, um-Nga	S. Africa			0.790‡
391		*Acacia melanoxylon*, R. Br.	Blackwood	E. Australia, Tasmania			0.675‡
392		*Acacia natalitia*, E. Mey.	u-Munga	S. Africa			0.700‡
393		*Adenanthera pavonina*, Linn.	Recheda, Yivè, redwood	India			0.898‡
394		*Afrormosia laxiflora*, Harms.	Ainyesan	W. Africa			0.802‡
395		*Afzelia africana*, Sm.	Aligna	W. Africa	Oven-dry		
396		*Afzelia* spp.	Merabau Ipil	Fed. Malay States Borneo	Green	0.718	
397		*Albizzia fastigiata*, Oliver	Flat crown, Nebelele, um-Hlandhloti	S. Africa		0.415	0.444
398		*Albizzia lebbek*, Benth.	Sirio, Siris, Kôkko, walnut	India			0.753‡
399		*Albizzia odoratissima*, Benth.	Suriya Mara, Thitmagyi	Ceylon			0.914‡
400		*Albizzia procera*, Benth.	Thitpyu, Sit, White Siris	India			0.737‡
401		*Bauhinia variegata*, Linn.	Kachnar, Bwèchin, Bwegyin	India			0.705‡
402		*Berlinia acuminata*, Soland.	Ekpagoy	W. Africa			0.891‡
403		*Brachystegia spicaeformis*, Benth.	Okwein	W. Africa	Air-dry		0.645
404		*Cassia siamea*, Lam.	Johor	Fed. Malay States	Air-dry		0.849
405		*Castanospermum australe*, A. Cunn.	Black bean	New South Wales, Queensland			0.837‡
406		*Cylicodiscus gabunensis*, Harms.	African greenheart, Okan	W. Africa			0.934‡
407		*Dalbergia latifolia*, Roxb.	East Indian rosewood, blackwood, Kala Shishâm	India			0.882‡
408		*Dalbergia sissoo*, Roxb.	Sissoo, Shishâm	India			0.770‡
409		*Detarium senegalense*, J. F. Gmel.	Ogwega	W. Africa			1.091‡

* Tension parallel to grain.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		2.93	5.37	618	0.086							3.65										(12)
		2.93	5.55	712	0.074							4.10										(12)
		3.52	7.00	849	0.084							3.98										(12)
		3.52	8.95	906	0.076							5.03										(12)
		3.52	8.35	909	0.076							5.08										(12)
		3.54	6.34	1157	0.060							4.32			0.237							(54)
		3.43	6.14	1037	0.059							3.79			0.666							(54)
			6.57	745								4.61			1.232							(10, 43)
	18	4.83	8.98	1490																		(21)
			7.21	855								4.28			1.030							(10, 43)
			< 19.67	1307								5.20			>0.317		7.02*					(11)
	41	5.01	8.90	1318	0.106		15.10	2135	0.599	107	2.66	4.77	1520	1.026	1.061	1.100	0.496	0.513	801	760	785	(38)
	16	8.44	16.07	2025								9.99			1.883							(10, 21, 31, 43)
			7.20	973								4.00			0.905							(10, 43)
	33	2.72	6.62	752	0.051																	(40)
0.690	50 10 0	4.23	9.36	1119	0.092							5.57			0.996							(8, 12, 55)
			11.98	1670																		(61)
			5.34	910																		(61)
		5.04	5.69	996	0.137																	(3)
	63	3.94	6.16	1155	0.076	0.654					2.22	3.04		0.604	0.699	0.860						(3, 4, 29)
	15	4.36	7.71	1140	0.094	0.499					2.90	3.69		0.821	1.010	1.104	0.300 10.13*	0.739	526	386	376	(3, 4, 29)
			7.53	1113																		(61)
			9.29	1363																		(61)
			11.39	1372																		(2, 61)
			9.03	1303																		(61)
	23		13.81	1676								7.94										(9, 37)
	14	9.39	17.33	2398																		(21)
		5.52	6.97	901	0.188																	(3)
			5.77	925																		(61)
	17		6.93–7.84									3.66–4.29										(6)
	20	3.30	6.46	1406																		(21)
	16	5.62	11.02	1623																		(21)
			5.89	886								3.41			0.907							(10, 43)
0.800	80 10 0	8.06	11.49	1254	0.292							6.44			0.918							(8, 12, 55)
	83		2.46									3.38			0.429							(22)
	13		5.56									4.71			0.485							(23)
		4.81	7.42	722	0.174							4.10			0.650							(54)
	25	9.98	10.75	1655											0.830		8.44*					(20)
			11.13	1262								<11.83										(31)
		2.42	5.78	698	0.048							4.27										(12)
			7.80	1138								5.45	1260		1.453		11.03*					(51, 58, 59)
		2.34	5.99	593	0.053							3.71										(12)
			10.13	1314								7.13			1.499							(10, 43)
		3.79	7.14	1284								4.68			0.648							(57)
0.639	9	7.41	12.66	1516	0.188	0.765					4.77	6.75	1550	1.208	1.326	1.589						(15)
	21	6.87	11.51	1628								6.35										(21, 37)
0.460	70 10 0	6.33	9.54	961	0.232							4.77			1.012							(8, 12, 50, 57)
			9.29	1157								6.73			1.433							(10, 43, 48)
		7.02	10.27	1220	0.224							6.58			0.902							(54)
			12.63	1456								7.45			1.733							(9)
			3.84	370								2.90			0.981							(10, 43)
		2.18	6.11	981								3.78			0.543							(57)
	10	6.82	12.13	1672	0.145	0.785					4.47	6.58	1673	1.062	1.136	0.973						(15)
	18	6.23	10.84	1392																		(21)
			8.87	1188								4.28	994		1.742		6.58*					(2, 59)
		5.44	8.98	1277								5.12			1.017							(57)
			13.64	1247								7.61										(9, 31)
			9.96	1146								7.49										(31, 43)
		6.43	11.36	1458								6.23			0.785							(57)

1	2	3	4	5	6	7	8
410		*Dialium platysepalum*, R. T. B.	Kranji	Fed. Malay States	Green	0.785	
411		*Erythrina caffra*, Thunb.	Kafirboom, um-Sinsi	S. Africa	Air-dry		0.240
412		*Hardwickia binata*, Roxb.	Anjan, Acha, Yepa	India			1.313‡
413		*Koompassia parvifolia*, Prain	Tualang	Fed. Malay States	Air-dry		0.657
414		*Milletia caffra*, Meissn.	Kaffir ironwood, um-Zimbiti	S. Africa			1.150‡
415		*Pericopsis mooniana*, Thw.	Nedun, Hedun	Ceylon			1.135‡
416		*Piptadenia africana*, Hook., f.	Ekhimi, Agboin, West African greenheart	W. Africa	Oven-dry		
417		*Pterocarpus indicus*, Willd.	Padauk	India	Air-dry		0.685
418		*Pterocarpus macrocarpus*, Kurz.	Burma Padauk	India			0.865‡
419		*Pterocarpus marsupium*, Roxb.	Bijasâl, Vengai	India			0.881‡
420		*Pterocarpus santalinus*, Linn., f.	Red Sanders, Lal Chandanum	India			1.202‡
421		*Pterolobium* sp.	Agba	W. Africa	Air-dry		0.463
422		*Sindora* sp.	Sepetir	Fed. Malay States	Air-dry		0.508
423		*Sophora tetraptera*, J. Mill., var. *grandiflora*, Hook., f.	Kohwai	New Zealand			0.884‡
424		*Virgilia capensis*, Lam.	Keur, vetch-leaved Virgilia	S. Africa			0.708‡
425		*Xylia dolabriformis*, Benth.	Ironwood of Burma and Arracan, Pyinkado, Jambu	India			0.961‡
426	*Linaceae*	*Ixonanthes icosandra*, Jack.	Pagar Anak	Fed. Malay States	Air-dry		0.697
427	*Loganiaceae*	*Buddleia salvifolia*, Lam.	Saliehout, Gwangi, sagewood	S. Africa			0.810‡
428		*Nuxia floribunda*, Benth.	Wild elder, Vlier, um-Quaqu	S. Africa			0.706‡
429		*Strychnos atherstonei*, Harv.	Cape Teak, Kajatenhout, um-Hamalala	S. Africa			0.780‡
430	*Lythraceae*	*Lagerstroemia flos-reginae*, Retz.	Pyinma, Ajhar, Jarul, Taman	India	Air-dry		0.566
431		*Lagerstroemia hypoleuca*, Kurz.	Pyinma, Pabda	India			0.641‡
432		*Lagerstroemia lanceolata*, Wall.	Nana, Benteak	India			0.850‡
433		*Lagerstroemia parviflora*, Roxb.	Indian Prima Vera, Dhauri, Lendia, Sida	India			0.849‡
434		*Lagerstroemia* sp.	Bungor	Fed. Malay States	Air-dry		0.513
435		*Lagerstroemia tomentosa*, Presl.	Burmese Lesa wood	India			0.802‡
436	*Magnoliaceae*	*Michelia champaca*, Linn.	Sapu, Champaca, saga	Ceylon			0.638‡
437		*Michelia excelsa*, Bl.	Magnolia, Bara champ, Gok	India			0.529‡
438	*Malvaceae*	*Hibiscus tiliaceus*, Linn.	um-Lolwa	S. Africa			0.760‡
439		*Thespesia populnea*, Soland.	Tulip tree, Portia tree, Suriya	India			0.806‡
440	*Meliaceae*	*Cedrela toona*, Roxb.	Red cedar, Toon, Tuni, Poma, Thitkado	Australia and India	Air-dry		0.479
441		*Chickrassia tabularis*, A. Juss.	Chikrassi, Arrodah, Yinma, Chittapong wood	India			0.785‡
442		*Chloroxylon swietenia*, DC.	Satinwood, Buruta, Mutirai	Ceylon			1.031‡
443		*Dysoxylon fraserianum*, Benth.	Rosewood	Australia			0.726‡
444		*Dysoxylon muelleri*, Benth.	Red bean	Australia			0.723‡
445		*Dysoxylon spectabile*, Hook., f.	Kohe Kohe	New Zealand			0.678‡
446		*Ekebergia capensis*, Sparrm.	Dog plum, Essehout, Cape ash	S. Africa		0.490	0.517
447		*Ekebergia meyeri*, Presl.	Essehout	S. Africa			0.540‡
448		*Entandrophragma candollei*, Harms.	Ikpwapobo	W. Africa			0.674‡
449		*Guarea* sp.	Scented mahogany, cedar, Obobo-Nufwa	W. Africa			0.814‡
450		*Guarea thompsoni*, Spr. and Hutch.	Obobo-Nikwi, cedar	W. Africa			0.774‡
451		*Khaya ivorensis*, A. Chev.	Mahogany, Ogwango	W. Africa			0.668‡
452		*Khaya senegalensis*, A. Juss.	Dry-zone mahogany, Ogwango	W. Africa			0.513‡
453		*Melia azedarach*, Linn.	Margosa, Nym tree, Persian lilac, bastard cedar, Thamaga	Ceylon			0.758‡
454		*Melia dubia*, Cav.	Lucumidella, Ceylon mahogany or cedar, Malai	Ceylon			0.327‡
455		*Pseudocedrela* sp.	Apopo	W. Africa			0.519‡
456		*Pteroxylon utile*, Eckl. and Zeyh.	Sneezewood, Nieshout, Mweri, um-Tati	S. Africa		0.956	0.991
457	*Monimiaceae*	*Doryphora sassafras*, Endl.	Sassafras	Australia			0.593‡
458	*Moraceae*	*Artocarpus chaplasha*, Roxb.	Kaita-da, Chaplash, Chram, Taungpeinnè	India			0.545‡
459		*Artocarpus hirsuta*, Lamk.	Aini, Ayani	India	Green Air-dry	0.516	
460		*Artocarpus integrifolia*, Linn., f.	Jak, Kanthal, Peinnè, Pilla	Ceylon			0.695‡
461		*Artocarpus lakoocha*, Roxb.	Dahu, Myauklot, Wonta	India			0.641‡
462		*Artocarpus nobilis*, Thw.	Del, Bedi-del	Ceylon			0.770‡
463		*Artocarpus rigida*, Bl.	Perian	Fed. Malay States	Air-dry		0.304
464		*Artocarpus* sp.	Keladang	Fed. Malay States	Green Air-dry	0.601	
465		*Chlorophora excelsa*, Benth. and Hook.	Iroko, Odum	W. Africa	Air-dry		0.545
466		*Ficus natalensis*, Hochst.	Wild fig, um-Tombi	S. Africa			0.410‡
467		*Ficus* sp.	Pulut Pulut	Fed. Malay States	Air-dry		0.336
468		*Sloetia sideroxylon*, Teijsm. and Binn.	Tempinis	Fed. Malay States	Air-dry		0.872

* Tension parallel to grain.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	23	7.73	13.07	2088																		(21)
0.250	10	1.17	1.93	240	0.032							1.29										(8, 12)
			11.92	1507								8.45										(31, 43)
	18	4.36	8.51	1560																		(21)
		8.09	11.83	1714	0.198							10.30										(12)
		7.13	11.28	1532	0.180							6.16			1.044							(54)
0.665	8	6.61	11.77	1508	0.151	0.556					4.68	6.75	1530	1.47	1.377	1.712						(15, 57)
	17	8.12	8.96	1537								5.21			0.956		10.16*					(10, 20, 31, 37, 43)
			10.99	879								8.78			1.647							(43, 47)
			8.73	1253								<14.02										(31)
			9.85	1271								10.00			2.620							(10, 31, 43)
	10	6.07	8.63	996	0.193	0.668					3.17	4.20	957	0.698	0.758	0.993						(15)
	17	3.90	6.77	1054																		(21)
		4.96	10.51	962	0.168																	(3)
		6.00	8.95	1040	0.193							4.47			0.954							(55)
			10.13	1280								6.10			1.386							(31, 43)
	16	5.77	11.65	1673																		(21)
		3.60	7.67	670	0.107							4.95										(12)
		7.21	10.42	1154	0.251							5.16			0.728							(55)
		2.64	7.08	806	0.045							5.21										(12)
	11	7.37	11.87	1271	0.243							6.10			1.402				792	645	640	(31, 35, 53)
			6.92	903								4.72			1.117							(10, 43)
			7.26									3.81			0.834							(9, 31, 43)
			11.46	1251								6.03			1.790							(9, 31, 43)
	19	4.72	8.35	1132																		(21)
			10.10	1147								5.96			1.388							(9, 44)
		3.30	5.49	792	0.072							2.47			0.530							(43, 54)
			7.13	812								3.95			0.700							(10, 43)
		2.34	6.71	698	0.053							4.21										(12)
		4.16	8.20	713	0.127							4.43			0.652							(54)
	12		6.98	950								5.48			1.028							(6, 31, 43, 59)
			7.77	873								6.99										(31, 43)
		5.71	9.68	1101	0.159							5.31			1.338							(31, 43, 54)
			8.37	1333								5.06	975		1.434		10.99*					(19, 58, 59)
			4.07	1086								4.88	720		1.596							(59)
		4.66	5.94	1014	0.119																	(3)
0.520	70, 10, 0	3.05	5.28	780	0.066							3.88										(8, 12)
		3.05	5.74	1043	0.059							3.78										(12)
		2.33	4.44	693								3.02			0.629							(57)
		3.08	5.13	754								2.68			0.638							(57)
		3.06	4.90	945								4.27			0.618							(57)
			<12.38	1079								4.56			>0.351		>4.24*					(11)
		2.30	4.40	867								2.87			0.533							(57)
		4.09	8.07	780	0.110							4.71			0.932							(54)
		2.08	4.02	520	0.047							2.14			0.336							(54)
		1.93	4.33	647								3.01			>0.410							(57)
1.000	25, 10, 0	9.09	13.41	1434	0.318							9.70			0.771							(8, 12, 48, 55)
			8.33	1382																		(61)
			5.97	693								4.87			0.906							(10, 43)
	80	4.82	7.52	1045	0.127		10.17	1440	0.411	76	2.99	4.14	945	0.580	0.724	0.614	0.358	0.394	481	440	470	(31, 42, 43, 62)
	13	6.19	9.37	1265			11.47			58	3.74	5.81		0.865	0.949	0.875			617	390	528	
		4.13	4.81	700	0.126							5.36			0.473							(31, 43, 54)
			10.76	1303								7.18			1.374							(10, 43)
		4.77	6.54	997	0.112							4.61			0.869							(54)
	15	2.78	4.88	773																		(21)
	61	5.62	10.27	1582																		(21)
	14	6.40	11.32	1652																		
	14	7.07	10.54	1227	0.216	0.773					5.28	5.75	1203	1.043	0.976	0.833	0.536	0.651	639	508	544	(11, 15, 18)
		2.46	3.75	528	0.064							2.76										(12)
	17	2.65	5.20	787																		(21)
	14	8.91	16.32	2030																		(21)

1	2	3	4	5	6	7	8
469	*Myristicaceae*	*Myristica irya*, Gaertn.	Black Chuglam, Maloh	India			0.833‡
470	*Myrsinaceae*	*Myrsine melanophlaeos*, R. Br.	Cape beech, Beukenhout, Magona	S. Africa		0.663	0.743
471		*Myrsine urvillei*, A. DC.	Mapau	New Zealand			0.991‡
472	*Myrtaceae*	*Angophora intermedia*, DC.	Narrow-leaved apple	New South Wales, Queensland			0.929‡
473		*Angophora lanceolata*, Cav.	Smooth-barked apple	New South Wales, Queensland			0.962‡
474		*Angophora subvelutina*, F. Muell.	Rough-barked apple	New South Wales, Queensland			0.769‡
475		*Backhousia myrtifolia*, Hook.	Grey myrtle	New South Wales, Queensland			1.042‡
476		*Eucalyptus accedens*, Fitzg.	Powder bark	Australia			
477		*Eucalyptus acerrula*, Hook., f.	Red gum	Tasmania			1.026‡
478		*Eucalyptus acmenioides*, Schau.	White mahogany	New South Wales, Queensland	Green	0.757	
479		*Eucalyptus amygdalina*, Labill.	Black peppermint	Tasmania			0.930‡
480		*Eucalyptus andrewsi*, J. H. M.	New England peppermint	New South Wales			0.849‡
481		*Eucalyptus australiana*, R. T. B. and H. G. S.	Narrow-leaved peppermint	New South Wales, Victoria			0.792‡
482		*Eucalyptus beyeri*, R. T. B.	Narrow-leaved ironbark	New South Wales			1.146‡
483		*Eucalyptus bicolor*, A. Cunn.	Flooded box	New South Wales			1.021‡
484		*Eucalyptus botryoides*, Sm.	Bangalay, mahogany	Queensland, Victoria			1.013‡
485		*Eucalyptus bridgesiana*, R. T. B.	Apple, woolly-butt	New South Wales, Victoria			0.906‡
486		*Eucalyptus calophylla*, R. Br.	Marri, red gum	W. Australia	Green	0.659	
					Air-dry		0.801
487		*Eucalyptus campanulata*, R. T. B. and H. G. S.	Stringybark	Australia			0.833‡
488		*Eucalyptus capitellata*, Sm.	Brown stringybark	Australia			0.994‡
489		*Eucalyptus citriodora*, Hook., f.	Citron-scented gum	Queensland			0.930‡
490		*Eucalyptus consideniana*, J. H. M.	White ash	New South Wales			0.930‡
491		*Eucalyptus cornuta*, Labill.	Yate gum	W. Australia	Green	0.959	
					Air-dry		1.015
492		*Eucalyptus corymbosa*, Sm.	Bloodwood	Australia			0.970‡
493		*Eucalyptus corynocalyx*, F. Muell.	Sugar gum	S. Australia			1.115‡
494		*Eucalyptus crebra*, F. Muell.	Narrow-leaved ironbark	Australia			1.120‡
495		*Eucalyptus delegatensis*, R. T. B.	Southern Mountain ash, Tasmanian oak	New South Wales, Victoria, Tasmania			0.657‡
496		*Eucalyptus diversicolor*, F. Muell.	Karri	W. Australia	Green	0.749	
					Air-dry		0.829
497		*Eucalyptus dives*, Schau.	Peppermint, messmate	Australia			1.157‡
498		*Eucalyptus drepanophylla*, F. Muell.	Messmate, ironbark	Australia			1.077‡
499		*Eucalyptus eugenioides*, Sieb.	White stringybark	E. Australia	Green	0.739	
500		*Eucalyptus fastigata*, H. D. and J. H. M.	Stringybark	New South Wales, Victoria			0.898‡
501		*Eucalyptus fergusoni*, R. T. B.	Bloodwood ironbark	New South Wales			1.162‡
502		*Eucalyptus fletcheri*, R. T. B.	River box	New South Wales, Victoria			1.066‡
503		*Eucalyptus fraxinoides*, H. D. and J. H. M.	White ash	New South Wales			0.722‡
504		*Eucalyptus globulus*, Labill.	Blue gum	India†	Green	0.676	
					Air-dry		0.806
				New South Wales, Victoria, Tasmania	Green	0.784	
					Air-dry		0.787
505		*Eucalyptus gomphocephala*, DC.	Tuart	S. W. Australia	Green	0.874	
					Air-dry		0.972
506		*Eucalyptus goniocalyx*, F. Muell.	Mountain gum, grey gum	New South Wales, Victoria, S. Australia			0.915‡
507		*Eucalyptus hemilampra*, F. Muell.	Mahogany	New South Wales			1.058‡
508		*Eucalyptus hemiphloia*, F. Muell.	Grey box, white box, brush box, gum-top box	Australia	Green	0.754	
					Air-dry		
					Green	0.884	
509		*Eucalyptus intermedia*, R. T. B.	Bloodwood	New South Wales			1.009‡
510		*Eucalyptus jacksonii*, J. H. M.	Red Tingle Tingle, stringybark	S. W. Australia	Green	1.170‡	
					Air-dry		0.887
511		*Eucalyptus laevopinea*, R. T. B.	Silvertop stringybark	Australia			0.802‡
512		*Eucalyptus largiflorens*, F. Muell.	Red box	Australia			1.245‡
513		*Eucalyptus leucoxylon*, F. Muell.	Blue gum	S. Australia			1.163‡
514		*Eucalyptus longicornis*, F. Muell.	Morrell	W. Australia	Green	0.900	
					Air-dry		0.915
515		*Eucalyptus longifolia*, Lk. and Ott.	Woollybutt, peppermint	New South Wales, Victoria	Green	0.769	

* Tension parallel to grain. † Not a native of this country.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
			11.68	1341								6.52			1.318							(10, 43)
	80																					
	10	4.32	7.07	1089	0.103							4.34			0.794							(8, 12, 55)
0.780	0																					
		4.66	9.75	825	0.154																	(3)
			11.74	1585																		(61)
			9.53	1339																		(61)
			6.91	1128																		(61)
			15.28	2120																		(61)
		8.47	10.20	1518																		(20)
			8.46	2132																		(2)
	44		10.21	1550	0.167							6.28	1713		0.971	1.041	7.39*					(2, 6, 24, 60)
			7.18	1960																		(2)
			6.83	1017																		(2)
			10.02	1446								6.41	1557		1.100		13.79*					(2, 59)
			12.22	1562																		(2)
			8.85	1114								4.01	982		1.160		11.54*					(2, 24, 59)
			10.93	1468								4.99	875		1.613		12.25*					(2, 59)
			6.12	945																		(2)
	75	6.32	7.98	1265								4.66	873		0.506		9.56*					(2, 20)
	12	8.86	11.67	1820								6.53	1389		0.808		14.20*					
			9.38	1455																		(2)
			12.17	1588																		(2)
			8.69	1189																		(2, 24)
			12.48	1637																		(2)
	32	8.93	11.74	1617								4.69	999		0.879		13.85*					(2, 20)
	12	11.95	15.12	1969								8.16	1336		1.178		17.02*					
			9.81	1408								6.97	1354		1.373		13.88*					(2, 6, 7, 24, 52, 59)
			7.24	1144								4.18	718		1.526		7.61*					(59)
			12.25	1620								6.95	1536		1.540		12.97*					(2, 24, 58, 59)
			9.55	1523																		(2)
	54	6.04	8.09	1230								3.87	926		0.633		9.25*					(2, 7, 20)
	12	9.53	12.16	1885								7.17	1425		0.738		13.18*					
			11.30									4.84					11.04*					(27)
			9.67	1245																		(24)
	39		11.22	1460	0.172							5.70	1524		1.023	1.164	8.61*					(2, 59, 60)
			12.42	1987																		(2)
			15.94	2174																		(2)
			8.40	931																		(2)
			13.26	1782																		(2)
	52	4.60	7.93	1483	0.082		12.45	1703	0.508	104	2.27	3.59	2266	0.591	0.875	1.002	0.422	0.661	601	569	542	(38)
	13	8.00	12.79	2242	0.163		16.24	2604	0.602	135	3.79	5.83	2390	0.826	0.998	1.532	0.672	0.864	756	692	535	
	42	6.22	8.47	1652								3.99	1231		0.728		15.07*					(2, 7, 20, 55, 56, 59)
	12	10.54	11.99	2355								6.24	1793		0.946		18.14*					
	43	6.54	8.30	1146								4.91	1261		0.682		9.35*					(2, 7, 20)
	12	11.18	12.58	1800								7.49	1332		0.925		11.60*					
			10.92	1402								5.11	1072		1.314		9.49*					(2, 59)
			11.50	1608																		(2)
	70	7.16	8.79	1406								4.50	1300		0.591		9.77*					(2, 20, 24, 59)
	12	10.68	11.38	1898								6.33	1673		0.759		11.53*					
	30		12.97	1919	0.248							6.36	1794		1.132	1.315	14.78*					(60)
			11.92	1679																		(2)
		6.28	8.51	1311								4.36			0.661		8.21*					(20)
	12	10.39	12.78	2063								7.21			0.914		11.03*					
			7.13	914																		(2)
			9.96	1146								5.57	819		1.273		10.57*					(59)
			11.71	1705								6.59	1322		1.476		14.57*					(7, 58, 59)
	30	8.16	10.97	1512								5.52	1287		0.858		11.38*					(20)
	12	8.61	11.88	1687								7.81	1413		0.844		12.65*					
	40		11.51	1670	0.207							5.80	1652		1.087	1.172	14.92*					(2, 58, 59, 60)

1	2	3	4	5	6	7	8
516		*Eucalyptus loxophleba*, Benth.	York gum	W. Australia	Green	0.949	
					Air-dry		0.958
517		*Eucalyptus macrorhyncha*, F. Muell.	Red stringybark	E. Australia			0.877‡
518		*Eucalyptus maculata*, Hook., f.	Spotted gum	New South Wales, Queensland	Green	0.726	
					Air-dry		0.715?
519		*Eucalyptus marginata*, Sm.	Jarrah, West Australian mahogany	W. Australia	Green	0.727	
					Air-dry		0.787
520		*Eucalyptus media*, Link.	Blackbutt	Australia			0.929‡
521		*Eucalyptus microcorys*, F. Muell.	Tallowwood	New South Wales, Queensland	Green	0.834	
					Air-dry		0.830?
522		*Eucalyptus microtheca*, F. Muell.	Coolibah	W. Australia	Air-dry		1.271
523		*Eucalyptus muelleriana*, A. W. Howitt	Yellow stringybark	Victoria			1.170‡
524		*Eucalyptus nanglei*, R. T. B.	Pink ironbark	Australia			1.106‡
525		*Eucalyptus nitens*, J. H. M.	Scrub box, silvertop gum	New South Wales, Victoria			1.127‡
526		*Eucalyptus obliqua*, L'Hér	Stringybark	Australia, Tasmania	Green	0.605	
					Air-dry		0.601?
527		*Eucalyptus paniculata*, Sm.	Grey ironbark	Australia	Green	0.905	
528		*Eucalyptus paniculata*, Sm. and *Eucalyptus crebra*, F. Muell.	Ironbark	New South Wales, Queensland	Green	0.915	
					Air-dry		0.915
529		*Eucalyptus patens*, Benth.	Blackbutt	W. Australia	Green	0.687	
					Air-dry		0.772
530		*Eucalyptus patentinervis*, R. T. B.	Mahogany	New South Wales			1.058‡
531		*Eucalyptus pellita*, F. Muell.	Mahogany	Queensland			0.994‡
532		*Eucalyptus phellandra*	Messmate	Australia			0.738‡
533		*Eucalyptus pilularis*, Sm.	Blackbutt	E. Australia	Green	0.755	
534		*Eucalyptus piperita*, Sm.	Sydney peppermint	E. Australia			0.918‡
535		*Eucalyptus planchoniana*, F. Muell.	Tallow-wood	New South Wales, Queensland			0.977‡
536		*Eucalyptus platyphylla*, F. Muell.	Poplar gum	Australia			1.111‡
537		*Eucalyptus polyanthemos*, Schau.	Red box	New South Wales, Victoria			1.086‡
538		*Eucalyptus propinqua*, H. D. and J. H. M.	Grey gum	New South Wales, Queensland	Green	0.742	
					Air-dry		0.730?
539		*Eucalyptus punctata*, D. C.	Grey gum	New South Wales, Queensland	Green	0.867	
540		*Eucalyptus raveretiana*, F. Muell.	Thozet's box, iron gum tree	Queensland			1.133‡
541		*Eucalyptus redunca*, Schau.	Wandoo, white gum	W. Australia	Green	0.989	
					Air-dry		1.015
542		*Eucalyptus regnans*, F. Muell.	Giant gum, swamp gum	Victoria, Tasmania	Green	0.594	
					Air-dry		0.587?
543		*Eucalyptus resinifera*, Sm.	Red mahogany, forest mahogany	New South Wales, Queensland	Green	0.812	
					Air-dry		0.802?
544		*Eucalyptus robusta*, Sm.	Swamp mahogany	E. Australia			0.913‡
545		*Eucalyptus rostrata*, Schl.	Murray red gum	E. Australia	Green	0.712	
					Air-dry		0.701?
546		*Eucalyptus saligna*, Sm.	Blue flooded gum, Sydney blue gum	New South Wales, Queensland	Green	0.681	
					Air-dry		0.672?
547		*Eucalyptus saligna*, Sm. var. *pallidivalvis*, R. T. B. and H. G. S.	Flooded gum	New South Wales			0.802‡
548		*Eucalyptus salmonophloia*, F. Muell.	Salmon gum	W. Australia	Green	0.897	
					Air-dry		0.944
549		*Eucalyptus siderophloia*, Benth.	Broad-leaved ironbark, red ironbark	New South Wales, Queensland			1.161‡
550		*Eucalyptus sieberiana*, F. Muell.	Mountain ash	Australia	Green	0.771	
551		*Eucalyptus squamosa*, H. D. and J. H. M.	Ironwood, scaly-barked red gum	New South Wales			1.090‡
552		*Eucalyptus stuartiana*, F. Muell.	Messmate, apple of Victoria	Victoria			1.208‡
553		*Eucalyptus tereticornis*, Sm.	Forest red gum	E. Australia			1.082‡
554		*Eucalyptus terminalis*, F. Muell.	Pale bloodwood	Australia			1.158‡
555		*Eucalyptus tesselaris*, F. Muell.	Carbeen, Moreton Bay ash	S. Australia, N. S. W. Victoria, Tasmania			1.142‡
556		*Eucalyptus viminalis*, Labill.	Ribbony gum, manna gum	Australia			0.974‡
557		*Eucalyptus virgata*, Sieb.	Mountain ash Ironbark	Australia Tasmania			0.877‡
558		*Eucalyptus wilkinsoniana*, R. T. B.	Small-leaved stringy-bark	New South Wales			0.882‡
559		*Eugenia brachyandra*, J. H. M. and E. B.	Red apple	Australia			0.593‡
560		*Eugenia coolminiana*, C. Moore	Coolamon	New South Wales			0.738‡
561		*Eugenia cordata*, Laws	Waterbesje, um-Doni, Mutwa	S. Africa			0.700‡

* Tension parallel to grain.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	30	7.03	8.59	1054								5.38	861		0.802		8.02*					(20)
	12	7.73	10.19	1265								6.96	833		0.900		9.14*					
			9.80	1373								6.23	1598		1.498							(2, 59)
	61	6.82	8.71	1442								4.08	1167		0.647		10.95*					(2, 6, 20, 24, 52, 58, 59, 60)
	12	10.54	11.32	1968								5.52	1863		0.668		13.57*					
	50	5.83	7.45	1019								4.39	939		0.661		9.42*					(2, 20)
	12	7.24	10.54	1462								6.36	1050		0.738		10.90*					
		8.24	12.83	1427	0.272																	(3)
	48	7.59	9.14	1374								4.22			0.633		9.84*					(2, 6, 20, 24, 52, 58, 59, 60)
	12	10.68	12.02	1793								5.62			0.746		11.60*					
	13	8.40	10.06	1181	0.313	0.512					5.42	6.98	1185	4.07	1.905	2.341	9.47*		1700	1670	1930	(2, 16, 20)
			11.23									5.75					10.54*					(27)
			13.72	1912																		(2)
			9.99									5.54					12.75*					(27)
	72	4.92	6.61	1195								3.27	1090		0.577		9.42*					(2, 3, 20, 27, 51, 59)
	12	10.97	11.74	2548								5.59	1673		0.984		14.62*					
	24		12.48	1867	0.213							6.62	1645		1.289	1.376	8.86*					(2, 6, 59, 60)
	40	8.75	10.26	1530								5.45			0.787		10.54*					(20)
	12	13.00	13.64	2390								7.80			0.984		13.07*					
	61	5.62	7.38	1160								3.58	876		0.626		9.31*					(20)
	12	7.73	9.98	1406								5.94	927		0.795		11.04*					
			10.04	1403																		(2)
			7.13	1004																		(2)
			9.86	1100																		(61)
	33		11.08	1634	0.198							6.06	1498		1.052	1.157	11.35*					(2, 6, 7, 24, 52, 58, 59, 60)
			9.80	1653								4.62	1258		1.365		13.63*					(2, 58)
			14.12	1912																		(2)
			11.16	1182																		(24)
			11.39	1943								5.99	1648		1.259		15.76*					(58, 59)
	64	6.54	8.02	1237								4.96	1054		0.619		8.65*					(6, 20)
	12	10.48	11.24	1968								5.91	1371		0.731		12.23*					
	33		11.22	1625	0.190							6.32	1504		1.181	1.257	10.42*					(2, 60)
			8.36	869																		(24)
	28	8.26	9.84	1300								5.85	1188		0.809		10.09*					(20)
	12	9.60	11.32	1539								7.63	1231		0.921		11.32*					
	70	4.29	6.15	1265								2.95			0.492		10.54*					(2, 20)
	12	9.00	10.19	2320								5.06			0.738		13.63*					
	52	7.86	9.28	1371								4.31			0.647		10.90*					(2, 6, 20, 24, 49, 58, 60)
	12	10.19	11.60	1897								6.01			0.689		14.34*					
			9.18	1388								5.02	1207		1.100		10.82*					(2, 58, 59)
	40	3.58	4.78	521								2.64			0.710		4.98*					(2, 20, 59)
	12	6.75	7.31	990								3.80			1.027		6.29*					
	67	6.89	8.22	1301								4.39	1090		0.619		10.87*					(2, 20, 24, 58, 59, 60)
	12	10.90	11.39	1877								6.01	1850		0.773		13.29*					
			12.92	1822																		(2)
	25	8.86	11.60	1477								5.69	910		0.851		11.88*					(20)
	12	10.54	14.13	1758								7.52	1054		1.336		13.50*					
			12.18	1649								5.83	1170		1.112		10.33*					(2, 24, 52, 59)
	34		12.24	1652	0.177							5.67	1234		0.546	0.586	9.80*					(2, 60)
			4.47	641																		(2)
			5.72	722																		(24)
			10.44	1292								6.09	1286		1.433		10.72*					(2, 24, 59)
			10.62	1134																		(24)
			10.03	1028																		(24)
			8.30	1262								3.92	875		0.936		9.32*					(2, 27, 59)
			8.76	1481								5.32	1268		1.483		12.24*					(2, 58, 59)
			13.58	1793																		(2)
			8.04	1193																		(61)
			8.26	1307																		(2)
		2.18	5.58	869	0.032							3.79										(12)

1	2	3	4	5	6	7	8
562		*Eugenia cotinifolia*, Jacq.	Clou	Mauritius			0.978‡
563		*Eugenia jambolana*, Lam.	Jaman, black plum, Thabye	India			0.769‡
564		*Eugenia maire*, A. Cunn.	Maire	New Zealand			0.790‡
565		*Eugenia maire*, A. Cunn. var. ?	Black Maire	New Zealand			1.159‡
566		*Eugenia ridleyi*, King.	Kelat	Fed. Malay States	Air-dry		0.689
567		*Eugenia* sp.	Pomme	Mauritius			0.547‡
568		*Leptospermum ericoides*, A. Rich.	Manuka, tea tree	New Zealand			0.943‡
569		*Melaleuca maideni*, R. T. B.	Bellbowrie tea tree	Queensland			0.754‡
570		*Melaleuca styphelioides*, Sm.	Prickly-leaved tea tree	New South Wales, Queensland			1.074‡
571		*Metrosideros robusta*, A. Cunn.	Northern Rata	New Zealand			1.045‡
572		*Planchonia andamanica*, King.	Red Bambwe	India			
573		*Rhodamnia argentea*, Benth.	Silver myrtle	New South Wales			0.817‡
574		*Syncarpia laurifolia*, Ten.	Turpentine	New South Wales	Green	0.672	
					Air-dry		0.672
575		*Tristania conferta*, R. Br.	Brush box	N. Australia, New South Wales	Green	0.738	
					Air-dry		0.730?
576		*Tristania laurina*, R. Br.	Water gum	E. Australia			0.962‡
577		*Tristania suaveolens*, Sm.	Swamp mahogany	New South Wales			0.905‡
578	*Ochnaceae*	*Lophira procera*, A. Chev.	Ironwood, Kaku, Ekki	W. Africa	Air-dry		0.930
579	*Olacaceae*	*Scorodocarpus borneënsis*, Becc.	Kulim	Fed. Malay States	Air-dry		0.737
580		*Strombosia javanica*, Bl.	Dedali	Fed. Malay States	Green	0.593	
581	*Oleaceae*	*Fraxinus excelsior*, Linn.	Ash	British Isles	Air-dry		
582		*Noronhia broomeana*, Horne	Sandal	Mauritius			0.891‡
583		*Notelaea ligustrina*, Vent.	Silkwood	New South Wales, Victoria, Tasmania			1.043‡
584		*Olea foveolata*, E. Mey.	Bastard ironwood, Ijzerhout, Marochani	S. Africa			1.010‡
585		*Olea hochstetteri*, Baker	Musharagi	E. Africa	Air-dry		0.825
						0.802	
586		*Olea laurifolia*, Lam.	Black ironwood, Regte Zwarte Ijzerhout, Igqwanxe	S. Africa			0.897
587		*Olea verrucosa*, Link.	Wild olive, Olyvenhout, um-Ngquma	S. Africa			1.122‡
588	*Oliniaceae*	*Olinia cymosa*, Thunb.	Mountain hard pear, red berry, Satyobe	S. Africa			0.890‡
589	*Palmae*	*Borassus flabellifer*, Linn.	Tâl, Tan, The Toddy, Palmyra palm	India			0.802‡
	Pinaceae, v. Coniferae						
590	*Pittosporaceae*	*Bursaria spinosa*, Cav.	Native box	Australia			0.871‡
591		*Bursaria spinosa*, Cav. var. ?	Prickly box	Australia			0.922‡
592		*Pittosporum tenuifolium*, Gaertn.	Birch, Mapau	New Zealand			0.965‡
593	*Proteaceae*	*Banksia integrifolia*, Linn.	White honeysuckle	Australia			0.577‡
594		*Banksia serrata*, Linn.	Red honeysuckle	Australia			0.802‡
595		*Banksia verticillata*, R. Br.	River Banksia	W. Australia	Green	0.473	0.501
596		*Embothrium wickhami*, Hill and F. Muell.	Satin silky oak	Australia			0.529‡
597		*Grevillea hilliana*, F. Muell.	Red silky oak	New South Wales, Queensland			0.994‡
598		*Grevillea robusta*, A. Cunn.	Silky oak	Australia			0.641‡
599		*Knightia excelsa*, R. Br.	Honeysuckle, Rewa Rewa	New Zealand			0.785‡
600		*Orites excelsa*, R. Br.	Silky oak	Australia			0.593‡
601		*Stenocarpus salignus*, R. Br.	Beef wood	New South Wales, Queensland			0.817‡
602		*Stenocarpus sinuatus*, Endl.	Fire-tree	Australia			0.738‡
603		*Xylomelum occidentale*, R. Br.	Native pear	W. Australia	Green	0.628	0.658 (12 % M. C.)
604	*Rhamnaceae*	*Alphitonia excelsa*, Reiss.	Red ash	Queensland			0.737‡
605		*Emmenosperma alphitonioides*, F. Muell.	Bone-wood	New South Wales, Queensland			0.849‡
						0.806	
606		*Rhamnus zeyheri*, Sond.	Red ivory, um-Nini, Niere	S. Africa			0.925.
607		*Zizyphus jujuba*, Lam.	Jujube tree, Hauthai, Bér, Bogri	India			0.784‡
608	*Rhizophoraceae*	*Anisophyllea laurina*, R. Br.	Monkey apple	W. Africa	Air-dry		0.708
609		*Bruguiera gymnorrhiza*, Lam.	Bakau Minyak	Fed. Malay States	Green	0.937	
610		*Bruguiera rheedii*, Bl.	Black or red mangrove	Australia			0.865‡
611		*Carallia calycina*, Benth.	Ubberiya	Ceylon			0.909‡
612		*Carallia integerrima*, DC.	Dawata, Kierpa, Maniawga, Andi	Ceylon			0.749‡
613		*Weihea africana*, Benth.	Musaisi	E. Africa			0.685
614	*Rosaceae*	*Leucosidea sericea*, Eckl. and Zeyh.	Oudehout, Dwa-dwa, um-Chicki	S. Africa	Air-dry		0.610‡
615		*Parinarium* sp.	Muntelor	Fed. Malay States	Green	0.729	
					Air-dry		
						0.796	
616		*Pygeum africanum*, Hook., f.	Bitter almond, red stinkwood, Dumisulu, Mueri	S. Africa			0.845
617	*Rubiaceae*	*Adina cordifolia*, Hook., f.	Haldu, Hnaw, Bansa	India			0.721‡
618		*Antirrhoea verticillata*, DC.	Loustau	Mauritius			0.614‡

* Tension parallel to grain.

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		5.38	16.77	1549								7.05			1.381							
			7.59	839								6.21										(31, 43)
		5.36	9.09	861	0.199																	(3, 28)
		9.77	15.90	1327	0.413																	(3)
	16	5.64	11.57	1976																		(21)
		3.95	6.64	756								3.97			0.695							(63)
		5.82	12.10	1164	0.165																	(3)
			6.99	899																		(61)
			11.26	1367																		(61)
		4.71	9.92	1188	0.139																	(3)
			8.26									3.85			1.378							(9)
			12.15	1416																		(61)
	74	5.83	7.33	1195								3.98	984		0.548		8.43*					(2, 6, 20, 24, 58, 59, 60)
	12	9.70	10.41	1652								5.38	1364		0.766		11.74*					
	65	6.47	7.91	1143								3.48			0.633		9.04*					(2, 20, 24, 60)
	12	10.33	11.04	1743								5.20			0.843		11.74*					
			9.56	1458																		(61)
			7.54	827																		(2, 24)
	17	9.73	16.08	1919	0.250	2.355					5.96	7.35	1921	1.701	1.640	1.863	0.861	1.324	1952	1727	1727	(11, 18)
	16	4.57	8.41	1336																		(21)
	40	3.94	7.83	1336																		(21)
0.55–0.78		3.76	11.53	1287								5.86										(5)
		6.44	10.18	1300								6.26			0.324							(63)
		5.67	13.15	1099	0.184																	(3)
		5.46	9.79	1613	0.109							7.08										(12)
	14		6.47									7.46			0.682							(22)
0.940	50 10 0	6.66	11.45	1460	0.183							7.16			0.769							(8, 12, 48, 55)
		4.45	10.07	1116	0.100							6.47			1.258							(12)
		3.92	8.18	744	0.111							5.70			0.958							(8, 12, 55)
			11.12	1490								8.36										(31, 43)
		5.06	9.56	972	0.152																	(3)
		6.33	12.02	1018	0.223																	(3)
		6.33	12.30	1045	0.212																	(3)
			5.67	752																		(61)
			9.54	1168																		(61)
	100	5.12	7.24	807											0.773		5.62*					(20)
			8.01	831																		(61)
			13.52	1963																		(2, 61)
			10.44	1208																		(61)
		4.71	8.15	949	0.134																	(3)
			7.24	1003																		(61)
			12.40	1554																		(61)
			11.43	908																		(61)
	43	4.57	5.39	594											0.647		4.92*					(20)
			10.74	1222																		(61)
			15.38	1723																		(2, 61)
0.970	60 10 0	4.69	9.86	1252	0.098							9.56										(12)
		4.11	5.48	672	0.140							4.37			0.713							(54)
	15	6.97	9.26	1175	0.215	0.668					3.73	4.49	1279	1.272	0.797	1.356						(17)
	20	7.03	14.23	2390																		(21)
			9.38	1620																		(61)
		4.03	7.09	1122	0.079							5.40			0.750							(54)
		3.76	7.82	886	0.085							5.31			1.001							(45, 54)
	11		14.20									6.40			0.745							(22)
		1.64	4.15	323	0.046							3.56										(12)
	32	4.08	9.13	1518																		(21)
	17	5.56	10.74	1630																		
0.870	50 10 0	2.99	7.48	786	0.065							5.32			0.984							(8, 12, 22)
			7.75	990								7.34										(31, 43)
		5.53	8.84	1159								4.63			1.048							(63)

1	2	3	4	5	6	7	8
619		*Mitragyna macrophylla*, Hiern.	Subaha, Ya-ya, Abura	W. Africa	Air-dry		0.503
620		*Plectronia mundtii*, Poepp.	Rock alder, Klip Esse, Sandulane	S. Africa			0.830‡
621		*Sarcocephalus esculentus*, Afzel.	Opepe, Kusiaba	W. Africa			0.806‡
622	*Rutaceae*	*Acronychia baueri*, Schott.	Brush ash	New South Wales, Queensland			0.849‡
623		*Calodendron capense*, Thunb.	Wild chestnut, Kastanjehout, Moeb-akalela, um-Baba	S. Africa			0.620‡
624		*Clausena inaequalis*, Benth.	um-Nukambiba	S. Africa			0.800‡
625		*Flindersia acuminata*	Putt's pine	Australia			0.577‡
626		*Flindersia australis*, R. Br.	Colonial teak, crow's ash	New South Wales, Queensland	Green	0.747	
627		*Flindersia bennettiana*, F. Muell.	She-teak	New South Wales, Queensland			0.850‡
628		*Flindersia chatawaiana*, F. M. Bailey	Queensland maple	Queensland			0.689‡
629		*Flindersia ifflaiana*, F. Muell.	Cairn's hickory, Queensland hickory	Queensland			0.928‡
630		*Flindersia oxleyana*, F. Muell.	Long jack	New South Wales, Queensland			0.737‡
631		*Murraya exotica*, Linn.	Satinwood, Marchula	India			0.994‡
632		*Toddalia lanceolata*, Lam.	White ironwood, Maroogoo, um-Zani	S. Africa		0.715	0.787
633		*Xanthoxylum thunbergii*, DC.	Knobthorn, Knopjsedoorn, um-Nun-gumabele	S. Africa			0.940‡
634	*Salicaceae*	*Populus* spp.	Poplar	British Isles	Air-dry		
635		*Salix caprea*, Linn.	Willow	British Isles			0.490‡
636	*Sapindaceae*	*Alectryon excelsum*, Gaertn.	Titoki	New Zealand			0.916‡
637		*Allophyllus zeylanicus*, Linn.	in-Quala	S. Africa			0.750‡
638		*Blighia* sp.	Ukpe-Nikwi	W. Africa			1.148‡
639		*Cupania anacardioides*, A. Rich.	Carrot-wood, Tuckeroo	New South Wales, Queensland			0.833‡
640		*Diploglottis cunninghamii*, Hook., f.	Native tamarind	New South Wales, Queensland			0.641‡
641		*Harpullia pendula*, Planch.	Tulip wood	New South Wales, Queensland			0.930‡
642		*Hippobromus alata*, Eckl. and Zeyh.	Paardepis, Ulwatile, u-Qume	S. Africa			0.990‡
643		*Ratonia tenax*, Benth.	Brush teak	New South Wales, Queensland			0.738‡
644		*Sapindus trifoliatus*, Linn.	Soapnut, Ritha	India			1.026‡
645	*Sapotaceae*	*Bassia* sp.	Belian	Fed. Malay States	Air-dry		0.904
646		*Dichopsis petiolaris*, Thw.	Tawenna	Ceylon			0.739‡
647		*Dichopsis* sp.	Mai-aug	Fed. Malay States	Air-dry		0.612
			Nyatoh	Fed. Malay States	Air-dry		0.569
648		*Imbricaria maxima*, Poir.	Natte	Mauritius			0.848‡
649		*Mimusops caffra*, E. Mey.	Red milkwood, Chole, um-Tunzi	S. Africa			0.850‡
650		*Mimusops elengi*, Linn.	Bukal, Mulsari, Kaya	India			0.961‡
651		*Mimusops littoralis*, Kurz.	Andaman bullet-wood, Dogala, Mowha, Katpali	India			1.058‡
652		*Mimusops obovata*, Sond.	Red milkwood, um-Tunzi, Amasetole	S. Africa			0.910‡
653		*Mimusops* sp.	Baku	W. Africa	Air-dry		0.623
654		*Payena utilis*, Ridl.	Belian, Betis	Fed. Malay States	Air-dry		1.002
655		*Sideroxylon grandiflorum*, A. DC.	Tambalacoque	Mauritius			0.883‡
656		*Sideroxylon inerme*, Linn.	White milkwood, Witte Melkhout, um-Qwashu	S. Africa			0.990‡
657	*Saxifragaceae*	*Anopterus glandulosus*, Labill.	Native laurel	Australia			0.750‡
658		*Carpodetus serratus*, Forst.	White Mapau	New Zealand			0.822‡
659	*Scrophulariaceae*	*Halleria lucida*, Linn.	um-Binza	S. Africa			0.910‡
660	*Sonneratiaceae*	*Duabanga sonneratioides*, Ham.	Kokan, Lampatia	India	Air-dry		0.461
661		*Sonneratia* sp.	Perepat	Fed. Malay States	Green	0.657	
662	*Sterculiaceae*	*Commersonia echinata*, Forst.	Kurrajong	Australia			0.465‡
663		*Dombeya mastersii*, Hook.	Mukao	E. Africa	Air-dry		0.527
664		*Heritiera fomes*, Buch.	Sundri, Pinlékanazo, Mawldá	India			1.074‡
665		*Heritiera littoralis*, Dryand.	Looking-glass tree, Chomuntri, Sundri, Pinlékanazo	Ceylon			1.209‡
666		*Pterospermum suberifolium*, Lam.	Vuinauku, Vincol	Ceylon			0.648‡
667		*Sterculia tragacantha*, Lindl.	Okoko	W. Africa			0.822‡
668		*Tarrietia trifoliolata*, F. Muell.	Stavewood	Australia	Air-dry		0.838
669		*Tarrietia utilis*, Hiern.	Attabini, Niankuma	W. Africa	Air-dry		0.497
670		*Triplochiton johnsoni*, C. H. Wright	Owawa, Obeche, Arere	W. Africa	Oven-dry		
671	*Symplocaceae*	*Symplocos grandiflora*, Wall.	Bumroti, Moat soom	India			
672	*Tiliaceae*	*Berria ammonilla*, Roxb.	Halmilla, Petwun, Trincomalee wood	Ceylon			0.801‡
673		*Echinocarpus australis*, Benth.	Maiden's blush	Australia			0.513‡
674		*Entelea arborescens*, R. Br.	Corkwood	New Zealand			0.189‡
675		*Grewia occidentalis*, Linn.	Kruisbesje, um-Nqabaza	S. Africa			0.730‡
676	*Ulmaceae*	*Aphananthe philippinensis*, Planch.	Native elm, Australian hickory	Queensland, New South Wales			0.737‡
677		*Celtis rhamnifolia*, Prest.	Kamdeboo, stinkhout, um-Vumvu, Witgalboom	S. Africa		0.636	0.699

* Tension parallel to grain

‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	12	5.45	7.21	1067	0.145	0.618					3.41	3.92	919	0.628	0.717	1.054	0.406	0.812	553	390	376	(18)
		3.16	7.53	908	0.057							5.89										(12)
			11.34	1345								5.72			> 0.547		5.42*					(11)
			13.88	1649																		(61)
		3.52	7.53	855	0.091							4.30										(12)
		4.34	7.89	1044	0.101							5.84										(12)
			8.84	1268																		(61)
	25		8.10	1145	0.136							5.34	1113		0.992	1.043	14.42*					(2, 6, 52, 58, 59, 60)
			14.82	1888																		(2, 61)
			10.19	1466																		(61)
			11.42	1550																		(24)
			13.33	1645																		(2, 61)
			10.80	1228								7.51			2.162							(10, 43)
0.820	40 10 0	5.48	11.58	1230	0.148							6.49										(8, 12, 48)
		3.66	8.03	1139	0.071							5.05										(12)
0.48		2.10	7.73	928								4.00										(5)
				832								3.24										(19)
		5.87	12.56	1113	0.173																	(3)
		5.16	9.61	1146	0.127							5.71										(12)
		5.83	9.14	1273								5.06			0.831							(57)
			12.96	1684																		(61)
			9.79	1363																		(2, 61)
			12.87	1711																		(2, 61)
		4.45	8.31	1005	0.112							6.15										(12)
			6.45	1163																		(61)
			8.38	992								6.37			2.075							(10, 43)
	19	5.69	12.99	1780																		(21)
		3.41	5.67	1253	0.048							5.44			0.762							(54)
	15	3.30	9.53	1687																		(21)
	17	5.02	8.66	1434																		(21)
		4.96	11.52	1360								6.28			0.878							(63)
		3.40	6.70	881	0.078							5.51										(12)
			16.35	1697								7.89			2.095							(10, 43)
			8.53	1008								5.42			1.101							(10, 43)
		2.58	8.62	844	0.044							4.62										(12, 48)
	13	5.99	8.72	987	0.191	0.677					3.44	4.17	1008	1.182	1.205	1.084	0.736	0.717	692	592	634	(18)
	17	9.97	16.80	2475																		(21)
		7.03	14.82	1756								6.55			1.019							(63)
		2.82	8.06	973	0.046							4.41										(12)
		4.20	7.09	576	0.177																	(3)
		4.05	8.98	810	0.127																	(3)
		3.91	9.38	1145	0.071							6.00										(12)
	11		5.97									5.26			1.003							(33)
	25	4.57	9.29	1343																		(21)
			6.72	843																		(61)
	10		5.42									4.92			0.408							(22)
			12.60	1131								< 20.48										(31, 43)
		5.65	10.18	1161	0.144							4.62			0.937							(54)
		3.08	6.69	677	0.074							3.05			> 0.342							(54)
		3.23	7.47	1389								4.44			0.647							(57)
	18		9.84–11.82									7.38–13.28										(6, 24)
	12	5.52	7.58	932	0.172	0.569					3.52	3.88	905	0.739	0.880	0.885	0.576	0.646	383	365	401	(18)
0.430	9			1069								4.85										(19)
			4.22	515								2.72			0.849							(10)
		6.21	10.87	1230	0.168							5.42			0.584							(43, 54)
			6.68	870																		(61)
		6.58	1.62	200	0.013																	(3)
		3.52	8.56	1001	0.068							6.03										(12)
			9.78	1284																		(61)
0.730	60 10 0	4.04	8.32	1200	0.082							5.54										(8, 12)

1	2	3	4	5	6	7	8
678		*Chaetachme aristata*, Planch.	um-Kovoti	S. Africa			0.780‡
679		*Trema guineensis*, Priemer	Pigeon wood, um-Bengele	S. Africa			0.450‡
680		*Ulmus* spp.	Elm	British Isles	Air-dry		
681	*Umbelliferae*	*Heteromorpha arborescens*, Cham. and Schl.	um-Bangandhlala	S. Africa			0.870‡
682	*Urticaceae*	*Villebrunea integrifolia*, Gaud.	Ban kotkora, Lipic	India			
683	*Verbenaceae*	*Avicennia officinalis*, Linn.	Grey mangrove	Australia			0.849‡
684		*Clerodendron glabrum*, E. Mey.	um-Qwaqwana	S. Africa			0.690‡
685		*Gmelina arborea*, Roxb.	Yamane, Gamhar	India			0.577‡
686		*Gmelina leichhardtii*, F. Muell.	White beech	Australia			0.787‡
687		*Tectona grandis*, Linn., f.	Teak, Sáka, Sáj, Ságun	India	Green	0.581	
					Air-dry		0.582
					Oven-dry		
688		*Vitex altissima*, Linn.	Milla, Nemili-adagu, Maila	India			0.977‡

*Tension parallel to grain. ‡ Bulk density calculated from weight and volume at time of test, no determination of moisture content having been made.

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(For a key to the periodicals see end of volume)

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DANISH WOODS

E. SUENSON

For testing methods, *see* the original literature

Index No.	Genus and species	Local name	Bulk density, air-dry	Moisture content	Static bending			Compression		Lit.
					Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Parallel to grain: Maximum crushing strength	Perpendicular to grain: Fiber strength at elastic limit	
			g/cm³	% of oven-dry wt.	kg/mm²	kg/mm²	kg/mm²	kg/mm²	kg/mm²	
690	*Abies pectinata*	Ædelgran	0.440	15				3.60		(2)
691	*Picea abies* L. *	Rødgran	0.430	18	3.23	5.57	880	2.95	0.00	(3)
			0.474	15	4.06					(1, 2)
692	*Pinus laricio* v. *Austriaca*, Endl.	Østerrigsk Fyr	0.506	14.2				2.93		(2)
693	*Pinus montana*, Mill.	Bjærgfyr	0.487–0.564	12.4				2.97–5.56		(2)
694	*Pseudotsuga Douglasii*, Carr.	Douglasie	0.490	15				3.24		(2)
695	*Quercus robur*, L.†	Eg	0.740	17	3.94	8.53	910	4.20	0.58	(3)

* Tensile strength, 4.30–7.80 kg/mm² with 33–49 % moisture content (1).
† *Quercus pedunculata*, Ehrh. = *Quercus sessiliflora*, Sm.

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9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
		2.11	5.58	826	0.032							4.29										(12)
		1.88	4.65	739	0.030							3.81										(12)
0.570–0.794		4.86	9.97	1470								7.10					9.56*					(1, 5, 25)
		3.05	5.97	888	0.060							3.81										(12)
			5.40	583								3.19			0.855							(10)
			9.27	1194																		(61)
		2.34	6.23	521	0.058							3.86										(12)
			7.45	1044								4.03			0.851							(9, 31)
			5.39	1006								4.68	960		1.211		6.28*					(59, 61)
	56	4.73	7.63	1093	0.116		11.15	1434	0.487	84	2.75	3.88	1291	0.734	0.721	0.828	0.399	0.508	405	450	449	(10, 31, 32, 38, 43)
	12	6.09	9.04	1195	0.176		12.75	1605	0.564	65	3.37	5.37	1317	0.969	0.939	0.920	0.391	0.502	456	467	485	
0.599	9	6.74	10.19	1243	0.209		12.74	1781	0.512	74	3.64	5.86	1242	1.124	0.884	1.030	0.590	0.734	474	477	535	
		5.74	10.38	1136	0.161							4.91			0.706							(54)

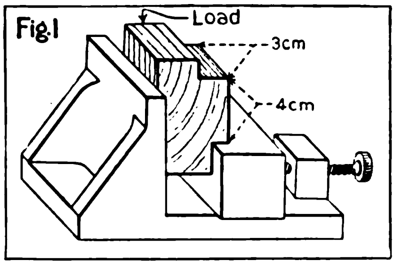
WOODS OF THE DUTCH EAST-INDIAN ARCHIPELAGO

The Forest Research Institute, Buitenzorg, Java

The values recorded below were determined in the Forest Research Institute in accordance with the standard testing methods of the "IV Kongress des Internationalen Verbandes für die Materialprüfungen, Brussels, September 1906," except in the following minor points:

1. The rate of strain increase in the bending and compression tests was 50 instead of 20 kg/cm² per minute.
2. The test piece shown in the figure was used in the shear tests.

The values given are the average for 4 to 10 specimens from two or more trees of different localities, except in the case of *Swietenia mahogani* Jack. and *Tectona grandis* L., cultivated in Java, for which 30 to 40 tests were made. All specimens tested were air-dried to the average moisture content shown.



Shearing test.

Index No.	Botanical name: Family	Botanical name: Genus and species	Local name	Bulk density, air-dry	Moisture content, air-dry	Static bending: Fiber stress at elastic limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work to elastic limit	Static bending: Work to maximum load	Compression parallel to grain: Fiber stress at elastic limit	Compression parallel to grain: Maximum crushing strength	Compression parallel to grain: Modulus of elasticity	Shear: Radial	Shear: Tangential	Hardness: End
				g/cm³	% oven-dry	kg/mm²			kg-mm/mm³		kg/mm²					kg/cm²
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
700	*Anacardiaceae*	*Buchanania arborescens*, Bl.	Popohan	0.48	16	3.20	6.83	900	0.0006	0.00593	1.74	3.47	930	0.67	0.78	431
701		*Gluta Renghas*, L.	Rengas	0.64	14	3.70	6.04	1260	.00027	.00333	3.30	4.74	1190	0.87	0.92	514
702	*Apocynaceae*	*Alstonia scholaris*, R. Br.	Pulaj	0.31	15	1.72	3.46	530	.00033	.00207	1.16	2.21	550	0.38	0.55	192
703	*Casuarinaceae*	*Casuarina equisetifolia*, Forst.	Chemara	0.71	19	5.70	9.55	1440	.00127	.00633	3.16	5.41				763
704	*Dipterocarpaceae*	*Dipterocarpus* sp.	Lagan, Kruing	0.68	15	4.99	8.79	1450	.00096	.00545	3.47	5.68		1.02	0.98	575
705		*Dryobalanops camphora*, Colebr.	Kapur	0.68	15	6.49	11.10	1585	.00147	.00814	4.31	6.18	1960	0.92	1.17	575
706		*Dryobalanops oblongifolia*, Dyer.	Petanang	0.66	16	5.67	9.71	1520	.00137	.00817	3.44	4.88	1550	0.86	1.09	545
707		*Dryobalanops oiocarpa*, v. Sl.	Sintok	0.50	14	2.55	4.66	1097	.00047	.00447	2.07	3.76		0.69	0.70	316
708		*Hopea Mengerawan*, Miq.	Merawan	0.57	14	6.35	8.00	1495	.00186	.00974	3.06	5.04	1400	0.68	0.87	583
709		*Hopea* sp.	Bankirai	0.72	17	7.88	11.69	1624	.00220	.00773	4.21	6.62	1795	0.99	1.15	686
710		*Shorea Balangeran*, Burck.	Belangiran	0.73	17	5.00	9.95	1212	.00113	.01053	3.16	5.09	1523	0.74	0.75	521
711		*Shorea* sp.	Banio	0.47	17	2.69	4.61	1030	.00040	.00507	1.53	3.83		0.54	0.44	286
			Damar merah	0.31	15	2.85	4.25	897	.00053	.00173	1.42	2.96				166
			Simantok	0.78	16	6.17	11.12	1565	.00153	.01093	3.80	5.79		1.08	1.35	630
712		*Vatica* sp.	Resak, Giam	0.79	16	6.42	10.60	1300	.00173	.00760	3.75	6.10	1585	1.15	1.24	871

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
713	*Flacourtiaceae*	*Homalium tomentosum*, Bth.	Dlingsem	0.81	16	5.90	12.50	1410	.00140	.01467	3.47	6.32	1560	1.03	1.41	1122
714	*Hamamelidaceae*	*Altingia excelsa*, Nor.	Rasamala	0.75	18	5.66	9.76	1365	.00130	.00730	3.20	5.72	1535	0.91	1.13	546
715	*Lauraceae*	*Eusideroxylon Zwageri*, T. et B.	Ijserhout, Onglenbelian	0.85	15	7.88	13.89	1522	.00227	.01147	4.03	7.46	1650	1.01	1.44	1120
716	*Leguminosae*	*Dalbergia latifolia*, Roxb.	Sono kling, Java-palis-sander	0.75	14	5.35	13.27	1387	.00120	.01567	3.15	6.36	1508	1.22	1.16	953
717		*Intsia amboinensis*, Thouars.	Merbau, Ipil	0.80	14	8.37	14.54	1840	.00233	.01202	3.78	8.19				963
718	*Meliaceae*	*Swietenia macrophylla*, King.	Mahogany	0.54	15	4.57	6.73	817	.00147	.00433	2.55	4.27	853	0.92	0.87	530
719		*Swietenia mahogani*, Jack.	Mahogany	0.54	14	4.66	7.10	890	.00147	.00493	2.20	4.04	925	0.83	0.98	435
720		*Toona Sureni*, Merr.	Suren	0.38	15	3.46	5.47	860	.00077	.00340	2.05	3.44	790	0.68	0.80	323
721	*Moraceae*	*Artocarpus elastica*, Reinw.	Bendo	0.35	15	3.06	4.47	810	.00067	.00341	1.52	2.92	735	0.47	0.48	260
722	*Olacaceae*	*Scorodocarpus borneensis*, Becc.	Kulim	0.81	16	6.33	12.48	1552	.00137	.01060	3.49	6.67	1732	0.86	1.27	887
723	*Rhizophoraceae*	*Combretocarpus Motleyi*, Hook. f.	Mrapat	0.67	16	3.86	6.95	1237	.00073	.00507	2.05	4.82	1060	1.00	0.81	475
724	*Sapindaceae*	*Schleichera oleosa*, Merr.	Kesambi	0.88	16	6.11	11.56	1680	.00133	.00893	3.07	5.91	1490	1.15	1.79	1428
725	*Sterculiaceae*	*Pterospermum javanicum*, Jungh.	Bajur	0.44	17	4.45	7.55	920	.00120	.00833	2.63	3.68	1095	0.56	0.74	382
726	*Taxaceae*	*Podocarpus imbricata*, Bl.	Aruh, Djamud-juh ki chemara	0.45	17	3.80	5.89	647	.00133	.00433	1.65	3.14				355
727	*Theaceae*	*Schima Noronhae*, Reinw.	Puspah, Seru	0.60	16	5.81	10.00	1488	.00133	.01056	3.34	5.49	1644	0.81	1.05	505
728	*Tiliaceae*	*Actinophora fragrans*, R. Br.	Walikukun	0.85	18	6.83	14.52	1520	.00172	.01974	4.26	7.10	1930	1.24	1.56	1220
729	*Ulmaceae*	*Celtis Wightii*, Planch.	Pendjalinan	0.72	16	4.20	11.60	1420	.00070	.02151	2.34	4.96	1590	1.13	1.31	775
730	*Verbenaceae*	*Tectona grandis*, Lin. f.	Djati, teak	0.59	14	5.75	8.90	1410	.00193	.01000	3.00	4.90	1316	0.82	0.97	396
731		*Vitex pubescens*, Vahl.	Laban	0.70	16	7.47	12.72	1510	.00207	.01040	4.69	6.84	1660	1.07	1.15	795

WOODS OF JAPAN AND EASTERN ASIA

HOMI SHIROSAWA

The values recorded below are based on tests made in the Central Forest Experiment Station (Ringyo-Shikenjo), Meguro, Tokyo, Japan.

The equations expressing the relation between the density and the stress were derived from the bulk density of air-dried specimens (moisture content, 16 %) and the green and oven-dry densities, given in the column "bulk density," are based on the volume in the air-dry condition (moisture content, 16 %).

The testing methods employed were those described above under "Woods of North America," with the following exceptions:

Static Bending.—Specimen 6 × 6 × 48 cm, 42 cm span mainly (85 % of all specimens); 0.1 cm per min.

Compression Parallel to Grain.—Specimen 6 × 6 × 6 cm mainly (83 % of all specimens); 0.1 cm per min.

Compression Perpendicular to Grain.—Specimen 6 × 6 × 6 cm mainly (85 % of all specimens); 0.1 cm per min.

Shear Parallel to Grain.—Shear over a 9 × 4 cm area; 0.1 cm per min.

Tension Parallel to Grain.—Tension over a 2.25 cm area; 0.1 cm per min.

Hardness.—Specimen 6 × 6 × 6 cm. Depth of indentation when the steel cylinder with 3 cm diameter hemispherical end is forced into the specimen with the load of 2000 kg against radial and tangential surfaces, and with 4000 kg against end surface.

Les valeurs mentionnées ci-dessous sont basées sur des essais effectués à la Central Forest Experiment Station (Ringyo Shikenjo) Meguro, Tokio, Japon.

Les équations exprimant la relation entre la densité et la tension ont été déduites de la densité apparente d'éprouvettes séchées à l'air (teneur en humidité, 16 %), et les densités du bois vert et du bois séché au four, données dans la colonne "bulk density" sont basées sur le volume de l'éprouvette séchée à l'air (teneur en humidité, 16 %).

Les méthodes d'essais employées sont celles déjà décrites dans "Bois de l'Amérique du Nord" à l'exception des suivantes:

Essai de flexion statique.—Eprouvette 6 × 6 × 48 cm, portée principalement 42 cm (85 % de toutes les éprouvettes); 0,1 cm par minute.

Compression parallèle à la fibre.—Eprouvette 6 × 6 × 6 cm principalement (83 % de toutes les éprouvettes); 0,1 cm par minute.

Compression perpendiculaire à la fibre.—Eprouvette 6 × 6 × 6 cm principalement (85 % de toutes les éprouvettes); 0,1 cm par minute.

Cisaillement parallèle à la fibre.—Cisaillement sur une surface de 9 × 4 cm; 0,1 cm par minute.

Traction parallèle à la fibre.—Traction sur une surface de 2,25 cm²; 0,1 cm par minute.

Dureté.—Eprouvette 6 × 6 × 6 cm. Profondeur de l'empreinte produite par un cylindre d'acier terminé par un hémisphère de 3 cm de diamètre forcé dans l'éprouvette avec une charge de 2000 kgs contre la surface radiale et tangentielle, et de 4000 kgs contre la surface terminale.

Den unten angegebenen Werten liegen Prüfungen zu Grunde, welche im Central Forest Experiment Station (Ringyo-Shikenjo) Meguro, Tokyo, Japan, gemacht worden sind.

Die Gleichungen, welche die Beziehung zwischen Dichte und Druck enthalten sind aus der durchschnittlichen Dichte des lufttrockenen Materials abgeleitet. (Feuchtigkeitsgehalt 16 %) und die Dichten des frischen und ofentrockenen Materials, die in der Kolonne "bulk density" stehen, gründen sich auf den lufttrockenen Zustand (Feuchtigkeitsgehalt 16 %).

Die angewendeten Prüfungsmethoden waren die gleichen, welche unter "Woods of North America" angegeben sind. Mit Ausnahme:

Statischer Biegeversuch.—Muster 6 × 6 × 48 cm durchschnittliche Spannweite 42 cm (85 % aller Muster); 0,1 cm in der Min.

I valori qui sotto riportati sono stati dedotti da prove eseguite nella Central Forest Experiment Station (Ringyo-Shikenjo), Meguro, Tokyo, Giappone.

Le equazioni che esprimono la relazione fra la densità e la pressione sono derivate dalla densità (volumetrica) del materiale asciugato all'aria (con 16 per cento d'acqua): le densità del materiale greggio e quello asciugato alla stufa, i quali si trovano nella colonna "bulk density," sono fondate sul volume del materiale asciugato all'aria (il tenuto d'acqua essendo 16 per cento).

I metodi impiegati per i saggi sono gli stessi riportati nel capitolo "Legni dell'America del Nord" fatta eccezione per quanto segue:

Flessione statica.—Provetta 6 × 6 × 48 cm, distanza media tra gli appoggi 42 cm (85 % di tutti i campioni); 0,1 cm al minuto.

Druck parallel zur Faserrichtung.—Muster 6 × 6 × 6 cm hauptsächlich (83 % aller Muster); 0,1 cm in der Min.

Druck senkrecht zur Faserrichtung.—Muster 6 × 6 × 6 cm hauptsächlich (85 % aller Muster); 0,1 cm in der Min.

Scherversuch parallel zur Faserrichtung.—Scherung über 9 × 4 cm, 0,1 cm in der Min.

Zug parallel zur Faserrichtung.—Zug über eine Fläche von 2,25 cm^2, 0,1 cm in der Min.

Härte.—Muster 6 × 6 × 6 cm. Eindruckstiefe eines Stahlzylinders mit halbkugelförmigem Ende (Durchmesser 3 cm) beobachtet, bei Belastung mit 2000 kg gegen die radiale und tangentiale Oberfläche und mit 4000 kg gegen die Endfläche.

Compressione parallela alla fibra.—Provetta 6 × 6 × 6 cm per la massima parte (83 % di tutti i campioni); 0,1 cm al minuto.

Compressione perpendicolare alla fibra.—Provetta 6 × 6 × 6 cm per la massima parte (85 % di tutti i campioni); 0,1 cm al minuto.

Taglio nel senso della fibra.—Taglio sopra 9 × 4 cm; 0,1 cm al minuto.

Trazione nel senso della fibra.—Trazione sopra una superficie di cm^2 2,25; 0,1 cm al minuto.

Durezza.—Provetta 6 × 6 × 6 cm. Profondità di impronta di un cilindro di acciaio con estremità emisferica (diametro 3 cm) osservata caricando con 2000 kg contro la superficie radiale e tangenziale e con 4000 contro la superficie terminale.

Strength and Related Properties

Index No.	Botanical name: Family	Botanical name: Genus and species	Local name	Bulk density: Green	Bulk density: Air-dry	Bulk density: Oven-dry	Moisture content green, %	Static bending: Fiber stress at elastic limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work to elastic limit	Compression parallel to grain—maximum crushing strength	Compression perpendicular to grain	Shear parallel to grain	Tension parallel to grain	Hardness: End	Hardness: Radial	Hardness: Tangential
				g/cm³				kg/mm²			kg-mm/mm³	kg/mm²				cm		
I. Equations expressing strength in terms of density																		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
							—	$F = 6.50\,D_0^{1.20}$	$F = 10.10\,D_0^{1.20}$	$F = 1350\,D_0^{1}$	$F = 0.0053\,D_0^{2}$	$F = 7.00\,D_0^{1}$	$F = 2.31\,D_0^{2}$	$F = 1.34\,D_0^{1}$	$F = 8.64\,D_0^{1}$	Actual value given below	Actual value given below	Actual value given below
II. Values as determined by tests—strength values expressed in percentage of equation values																		
751	*Aceraceae*	*Acer japonicum*, Thunb.	Hauchihakaede		0.72	0.60			98	88		87		105	71		0.15–0.18	0.12–0.27
752		*Acer palmatum*, Thunb.	Kaede	0.96	0.70	0.60	60		85	145		83		116	136	0.54	0.36	0.36
753		*Acer pictum*, Thunb. var. *typicum*, Koidz.	Itayakaede	0.86	0.67	0.57	54		83	90		100		98	99	1.08	0.18	
754		*Acer rufinerve*, S. and Z.	Urihadakaede	0.88	0.59	0.51	73		84	96		87		117	108	2.10		
755	*Anacardiaceae*	*Rhus vernicifera*, DC.	Urushi	0.88	0.51	0.44	100		118	105		136			127	0.09		
756	*Aquifoliaceae*	*Ilex crenata*, Thunb.	Inutsuge	1.04	0.72	0.63	65		74			81			75			
757		*Ilex macropoda*, Miq.	Aohada		0.66	0.57			106			108				0.12		
758	*Araliaceae*	*Kalopanax ricinifolius*, Miq.	Harigiri	0.83	0.54	0.47	75		105	105		91	99	101	84	1.08	0.42	0.36–0.42
759	*Betulaceae*	*Alnus firma*, S. and Z. var. *Sieboldiana*, Winkel.	Yashabushi		0.64	0.55			72	54		76		91		0.45		
760		*Alnus incana*, Willd. var. *sibirica*, Spach.	Yamahannoki	0.75	0.50	0.40	88		72	55		90			99	3.00	0.90	0.90
761		*Alnus japonica*, S. and Z.	Hannoki	0.69	0.50	0.42	60		95	77		101		87	96	3.00		
762		*Betula carpinifolia*, S. and Z.	Midzume		0.77	0.66		83	85	81	98	87		108	84			
763		*Betula Ermanni*, Cham. and Schl. var. *japonica*, Koidz.	Makamba	1.01	0.63	0.55	84		127	132		107			107			
764		*Betula japonica*, Sieb.	Shirakamba		0.70	0.60		75	84	77	123	88		101	110	1.05	0.36	0.18–0.42
765		*Betula Maximowicziana*, Regel.	Saihadakamba		0.68	0.58			118	72		96				0.06		
766		*Betula Schmidtii*, Regel.	Onoorekamba		0.86	0.75			120	146		122		125	108	0.03		
767		*Betula ulmifolia*, S. and Z.	Yogusominebari	0.91	0.70	0.60	52	110	107	155	116	109	90		97	0.03		
768		*Carpinus cordata*, Bl.	Sawashiba	0.93	0.71	0.57	63		110	114		100		111		0.09		
769		*Carpinus japonica*, Bl.	Kumashide	1.00	0.72	0.58	72		133	93		104		137	129			0.06
770		*Ostrya italica* Scop. var. *virginiana*, Winkel.	Asada		0.70	0.60			89	90		109	79	110	77	0.06	0.21	0.12
771	*Buxaceae*	*Buxus japonica*, Muell. Arg.	Tsuge	1.01	0.75	0.65	55		124	70		91				0.03		
772	*Cornaceae*	*Cornus contorversa*, Hemsl.	Midzuki	0.90	0.60	0.50	80		88	65		98		99	84	0.90		0.12–0.15
773	*Ebenaceae*	*Diospyros lotus*, L.	Mamegaki		0.60	0.50			99	71		85			81	0.84	0.15–0.18	
774	*Euphorbiaceae*	*Bischoffia javanica*, Bl.	Akagi		0.75	0.65		70	75	88	47	57		97	127			
775	*Fagaceae*	*Castanea sativa*, Mill.	Kuri	0.98	0.60	0.52	89		81	81		91	90	96	89	3.00	0.42–0.57	0.12–0.80
776		*Castanopsis taiwaniana*, Hay.	Kurikashi		0.77	0.66		98	90	111	63	74						
777		*Fagus Sieboldi*, Endl.	Buna	1.08	0.66	0.57	90	128	108	128	100	117		100	110	0.30	0.54	0.30
778		*Pasania cuspidata*, Oerst.	Shii	1.28	0.62	0.54	137	104	103	91	108	94		92	107		0.33	0.39–0.48

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
779		*Pasania glabra*, Oerst.	Shiribukagashi		0.69	0.60			106	88		120						
780		*Quercus acuta*, Thunb.	Akagashi	1.15	0.85	0.73	58	103	92	94	82	80		96	107	0.03	0.06	0.03–0.05
781		*Quercus amygdalifolia*, Skan.	Amigashi		1.16	0.93		91	74	102	50	75		75	102		0.42	0.36
782		*Quercus crispula*, Bl.	Ôhnara	1.02	0.73	0.63	62	71	75	91	89	98		85	77	0.06	0.12	
783		*Quercus gilva*, Bl.	Ichiigashi	1.05	0.80	0.68	54	122	108	89	88	85		94	98	0.09	0.15–0.21	0.12–0.15
784		*Quercus glandulifera*, Bl.	Konara	1.11	0.75	0.65	71	90	89	97	97	95		87	119	0.06	0.09	0.09
785		*Quercus glauca*, Thunb.	Arakashi	1.17	0.82	0.70	67		102	117	77	88		100	91	0.03	0.06–0.18	0.06–0.09
786		*Quercus myrsinaefolia*, Bl.	Shirakashi	1.11	0.85	0.72	54	95	96	70	78	89		115	84	0.03	0.03–0.06	0.03–0.05
787		*Quercus phyllireoides*, A. Gr.	Ubamegashi	1.24	0.85	0.74	68								147			
788		*Quercus serrata*, Thunb.	Kunugi		0.84				70	68		95		89	110	0.03		
789		*Quercus stenophylla*, Makino.	Urajirogashi	1.08	0.83	0.70	54	139	126	134	88	103		97	113	0.03		
790	*Ginkgoaceae*	*Ginkgo biloba*, L.	Ichō	0.84	0.44	0.38	111		104	92		100		104	71		1.38–1.50	1.20–1.38
791	*Hamamelidaceae*	*Distylium racemosum*, S. and Z.	Isunoki	1.31	0.96	0.83	58		115	118		92		103	84	0.03		
792	*Hippocastanaceae*	*Aesculus turbinata*, Bl.	Tochinoki	0.70	0.60	0.50	40	113	113		105	92		113	111			
793	*Juglandaceae*	*Juglans mandschurica*, Maxim.	Manshūgurumi		0.48	0.42		117	110	143		128						
794		*Juglans Sieboldiana*, Maxim.	Onigurumi	0.90	0.54	0.47	92	107	100	132	97	113	125	111	136	1.02	0.33–0.85	0.33–0.66
795		*Pterocarya rhoifolia*, S. and Z.	Sawagurumi	0.56	0.40	0.35	60		126	69		91	104	107	138	3.00		
796	*Lauraceae*	*Actinodaphne lancifolia*, Meisn.	Kagonoki	1.03	0.71	0.63	64		77	83		77		109			0.02	0.06
797		*Cinnamomum camphora*, Ness.	Kusu	0.97	0.55	0.45	116		71	95		106	99	75	66		0.96	0.60
798		*Cinnamomum pedunculatum*, Ness.	Yabunikkei	0.89	0.55	0.46	94		70	81		86		103	90	3.00	0.84	0.72
799		*Machilus Thunbergii*, S. and Z.	Tabu	1.01	0.69	0.55	84	76	74	107	105	107	106	83	114	0.06		0.42
800	*Leguminosae*	*Acacia confusa*, Merril.	Sōshiju		0.96	0.77		60	67	69	41	60						
801		*Albizzia Julibrissin*, Durraz.	Nemunoki	0.86	0.55	0.47	83		86	74		89			159			0.30
802		*Gleditschia horrida*, Makino.	Saikachi	1.03	0.74	0.64	61		95	87		92				0.09	0.09–0.15	0.09–0.12
803		*Maackia amurensis*, Rupr. and Maxim.	Inuenju	0.98	0.75	0.63	56		107	95		78	79	106	112	0.06		0.12
804	*Magnoliaceae*	*Magnolia hypoleuca*, S. and Z.	Hōnoki	0.86	0.51	0.44	84		98	116		92	110	113	113	3.00	0.27	0.24
805		*Magnolia Kobus*, DC.	Kobushi	0.75	0.60	0.50	50		86	80		107		91	95	0.06		
806	*Moraceae*	*Ficus retusa*, L. var. *nitida*, Miq.	Gajumaru	0.90	0.58	0.50	80		61	52		83						
807		*Morus alba*, L. var. *stylosa*, Bureau	Yamaguwa	0.98	0.67	0.58	69		100	85		102			116	0.06	0.12	0.06
808	*Myricaceae*	*Myrica rubra*, S. and Z.	Yamamomo	1.08	0.67	0.58	86		96	93		113		98	81	0.12		
809	*Oleaceae*	*Fraxinus Bungeana*, DC. var. *pubinervis*, Wg.	Toneriko	1.02	0.71	0.60	70		149	103		103		98	111		0.06–0.09	0.06
810		*Fraxinus longicuspis*, S. and Z.	Aotago		0.70	0.61			110	86		100		100				
811		*Fraxinus mandschurica*, Rupr.	Yachidamo	0.94	0.62	0.54	74		92	115		108	89	105	119		0.82	0.48
812		*Fraxinus Spaethiana*, Lingelsh.	Shioji	0.90	0.66	0.56	61	125	137	117	67	116		100	108	0.06		
813	*Pinaceae*	*Abies firma*, S. and Z.	Momi	0.97	0.48	0.42	131	106	105	139	126	105	98	101	122	3.00	0.63–1.44	0.30–1.17
814		*Abies sachalinensis*, Mast.	Todomatsu	0.82	0.41	0.35	134	95	96	106	118	125	106	111	98	3.00		
815		*Abies Veitchii*, Lindl.	Shirabe	0.73	0.40	0.33	121	88	100	93	118	124	97	124	94	3.00		1.44–1.80
816		*Chamaecyparis formosensis*, Matsum.	Benihi		0.37	0.32		98	97	106	65	103			94			
817		*Chamaecyparis obtusa* form. *formosana*, Hayata.	Taiwanhinoki		0.48	0.41		100	119	131	68	98			113			
818		*Chamaecyparis obtusa*, S. and Z.	Hinoki	0.98	0.46	0.40	145	132	125	115	134	123	106	110	93	3.00		1.08
				*	0.43	0.37		99	94	146		116	88					
819		*Chamaecyparis pisifera*, S. and Z.	Sawara	0.80	0.35	0.30	167		102	121		109		98	70	3.00		3.00
820		*Cryptomeria japonica*, Don.	Sugi	0.89	0.40	0.34	162	125	129	111	118	141	111	102	81	3.00		0.90–1.14
				†	0.36	0.31		121	131	75	131	107						
821		*Larix dahurica* var. *Principis Rupprechtii*, Rehd. and Wilson.	Chōsenkaramatsu		0.67	0.56		82	80	81		99		68	121			
822		*Larix leptolepis*, Gord.	Karamatsu	0.95	0.58	0.50	90	101	97	99	101	109	86	115	104	0.15	0.42	
823		*Libocedrus macrolepis*, Benth.	Shōnanboku		0.69			69	74	76	53	76						
824		*Picea ajanensis*, Fisch.	Ezomatsu	0.71	0.42	0.37	92	108	103	96	117	112	106	116	126	3.00		3.00
825		*Picea Glehnii*, Mast.	Akaezomatsu		0.47	0.41		153	141	134	137	153	96	104	154	3.00		3.00
826		*Picea Hondoensis*, Mayr.	Tōhi		0.43	0.38		100	106	112	153	119	101	103	110	3.00	1.14	3.00
827		*Pinus densiflora*, S. and Z.	Akamatsu	0.95	0.52	0.46	98	137	135	110	101	95	79	97	92	3.00	1.14	
828		*Pinus koraiensis*, S. and Z.	Chōsenmatsu	0.91	0.51	0.45	102	60	70	65	101	66		69	56	3.00	1.14–1.20	
829		*Pinus Thumbergii*, Parl.	Kuromatsu	0.97	0.53	0.47	106		100	110		125		96	71	3.00	0.42–1.65	1.20
830		*Pseudotsuga japonica*, Shirasawa.	Togasawara	0.94	0.50	0.43	119		103	127		131		116	81	3.00		3.00
831		*Sciadopitys verticillata*, S. and Z.	Kōyamaki		0.50	0.45			95	122		87		108	93	3.00		
832		*Taiwania cryptomeriodes*, Hay.	Taiwansugi		0.47	0.40		101	105	121	43	105						
833		*Thuja japonica*, Maxim.	Nezuko	0.61	0.37	0.32	91		95	86		115		112	74	3.00		3.00
834		*Thujopsis dolabrata*, S. and Z.	Hiba	0.97	0.50	0.44	120	113	109	132	115	115	87	89	79	3.00	3.00	1.44
835		*Tsuga Sieboldii*, Carr.	Tsuga	1.02	0.53	0.45	117	124	120	127	121	137	94	128	104	3.00	0.30–0.54	0.21–0.42
836	*Rosaceae*	*Micromeles alnifolia*, Koidz.	Adzukinashi	0.80	0.60	0.50	60		84	77		97		97	74	0.06		
837		*Photinia villosa*, DC.	Ushikoroshi	1.16	0.90	0.80	46		95	71					72	0.06	0.03	0.03
838		*Prunus donarium*, Sieb. subsp. *elegans*, Koidz. var. *glabra*, Koidz.	Yamazakura	1.05	0.67	0.58	81		91	97		73	96	102	116	0.24	0.12	0.09–0.12
839		*Prunus Grayana*, Maxim.	Uwamizuzakura	0.79	0.62	0.52	52								117			
840		*Prunus spinulosa*, S. and Z.	Rinboku	1.03	0.75	0.65	59		101	92		92		99	117	0.12	0.06–0.09	0.06–0.09
841	*Rutaceae*	*Phellodendron amurense*, Rupr.	Kihada	0.64	0.48	0.42	52		104	125		113	122	102	131	3.00	0.72–0.78	0.18–0.42
842	*Salicaceae*	*Populus balsamifera*, L.	Deronoki	0.83	0.38	0.33	152		88	114		85	106	94	82	3.00		
843		*Populus tremula*, L. var. *villosa*, Wesm.	Yamanarashi	0.70	0.48	0.40	75	111	111	97	71	118	120	131	147	3.00		
844	*Scrophulariaceae*	*Paulownia tomentosa*, Bail.	Kiri	0.56	0.31	0.27	107		119	96		107		110	86	3.00		3.00
845	*Simarubaceae*	*Picrasma quassioides*, Benn.	Nigaki	0.70	0.58	0.50	40		96	139		94	116	117	111	0.41	0.48	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
846	*Styracaceae*	*Styrax japonica*, S. and Z.	Egonoki	0.97	0.60	0.52	87		114	141		105		104	151	0.06		
847	*Taxaceae*	*Podocarpus Nageia*, R. Br.	Nagi	0.88	0.55	0.47	82		97	157		127		117	56	0.12		0.60
848		*Taxus cuspidata*, S. and Z.	Ichii	0.90	0.58	0.50	80		128	73		147	138	108	67	0.12	0.33	0.27
849		*Torreya nucifera*, S. and Z.	Kaya	1.03	0.56	0.48	115		107	96		118	118	92	111			
850	*Tiliaceae*	*Tilia japonica*, Engler.	Shinanoki		0.51	0.45			86	122		113		98	113	3.00	0.90	0.78
851	*Trochodendraceae*	*Cercidiphyllum japonicum*, S. and Z.	Katsura	0.58	0.45	0.38	53	71	75	88	90	89		103	80	0.09	1.20	1.02
852		*Euptelaea polyandra*, S. and Z.	Fusazakura	0.93	0.64	0.51	82		95	95		94		83	87	0.57	0.18–0.27	0.12–0.18
853	*Ulmaceae*	*Aphananthe aspera*, Planch.	Mukuenoki	1.02	0.68	0.58	76		93	107		100		116	125	0.45		
854		*Celtis sinensis*, Pers.	Enoki	0.94	0.60	0.52	81		77	74		79		89	97	1.26		
855		*Ulmus campestris*, Sm. var. *laevis*, Planch.	Harunire	0.94	0.62	0.54	74		81	97		70		86	131		0.42	0.36
856		*Ulmus campestris*, Sm. var. *major*, Planch.	Niganire	0.90	0.60	0.50	50		65	62		60		84	54			
857		*Ulmus montana*, Sm. var. *laciniata*, Trautv.	Ohiōnire	0.90	0.57	0.50	80		105	149		101		108				
858		*Ulmus parvifolia*, Jacq.	Akinire	0.94	0.61	0.53	77		87	71		73			94			
859		*Zelkowa acuminata*, Planch. form. *Keaki.*	Keaki	1.06	0.70	0.60	77	112	142	127	71	117	127	109	122	0.06	0.12	0.12

* Kiso-district in Honshû.
† Obi-district in Kyûshû.

THE WOODS OF MEXICO, CENTRAL AND SOUTH AMERICA AND THE WEST INDIES

Samuel J. Record

With the exception of the bulk density values recorded below, the available published data on mechanical properties of woods native to these countries are of doubtful reliability.

Bulk Density of Thoroughly Air-dry Samples

Values determined in the laboratory of the Yale School of Forestry

Index No.	Family	Genus and species	Common name	Place of growth of material tested	D_d g/cm^3
860	*Acanthaceae*	*Bravaisia floribunda*, DC.	Sancho-araña	Colombia	0.53
861	*Amygdalaceae*	*Licania hypoleuca*, Benth.	Chozo	Guatemala	1.03
862		*Moquilea tomentosa*, Benth.	Oity	Brazil	0.98
863	*Anacardiaceae*	*Anacardium rhinocarpus*, DC.	Espavé	Panama	0.54
864		*Astronium balansae*, Engl.	Urunday	Argentina	1.00–1.30
865		*Astronium fraxinifolium*, Schott.	Gonçalo Alves	Brazil	0.85–1.00
866		*Loxopterygium sagotii*, Hook. f.	Hooboballi	British Guiana	0.60–0.70
867		*Tapirira guianensis*, Aubl.	Duka	British Guiana	0.54
868		*Schinopsis lorentzii*, Engl.	Quebracho colorado	Argentina	1.15–1.35
869	*Anonaceae*	*Oxandra lanceolata*, (Sw.) Baill.	Yaya, lancewood	Cuba	0.98
870	*Apocynaceae*	*Aspidosperma polyneuron*, Muell. Arg.	Peroba rosa	Brazil	0.70
871		*Aspidosperma quebracho-blanco*, Schl.	Quebracho blanco	Argentina	0.90–1.00
872		*Aspidosperma tomentosum*, Mart.	Guatambú	Brazil	0.77
873		*Aspidosperma vargasii*, C. DC.	Amarillo	Venezuela	0.90–0.95
874	*Aquifoliaceae*	*Ilex* sp.	Kakatara-balli	British Guiana	0.80
875	*Araliaceae*	*Didymopanax morototoni*, (Aubl.) D. and P.	Yagrume	Tropical America	0.45
876	*Betulaceae*	*Alnus* sp.	Jaul	Costa Rica	0.47
877	*Bignoniaceae*	*Crescentia cujete*, L.	Cujete	Tropical America	0.60
878		*Jacaranda copaia*, (Aubl.) D. Don	Fotui	British Guiana	0.40–0.47
879		*Tabebuia donnell-smithii*, Rose	Prima vera	Mexico	0.45–0.50
880		*Tecoma*, spp.	Lapacho, guayacan	Tropical America	0.95–1.25
881		*Tecoma pentaphylla*, Juss.	Roble	Tropical America	0.60–0.68
882		*Tecoma peroba*, Record	Ipé peroba	Brazil	0.70–0.83
883	*Bombacaceae*	*Bombacopsis* spp.	Saqui-saqui	Venezuela	0.41–0.59
884		*Bombax* spp.	Imbirussú	Brazil	0.24–0.40
885		*Cavanillesia platanifolia*, H. B. K.	Bongo	Panama	0.10
886		*Ceiba pentandra*, (L.) Gaertn.	Ceibo	Tropical America	0.40–0.45
887		*Chorisia speciosa*, St. Hil.	Samohú	Argentina	0.35–0.45
888		*Ochroma* spp.	Balsa	Tropical America	0.12–0.20
889		*Quararibea* sp.	Veroity	Brazil	0.72
890	*Boraginaceae*	*Auxemma gardneriana*, Miers	Páo branco	Brazil	0.70
891		*Cordia gerascanthoides*, H. B. K.	Boscote	Mexico	0.97
892		*Cordia gerascanthus*, L.	Laurel	Central America	0.61
893		*Cordia goeldiana*, Huber	Frei-jo	Brazil	0.60
894		*Patagonula americana*, L.	Guayabí	Argentina	0.85–0.90
895	*Burseraceae*	*Bursera gummifera*, (L.) Sargent	West Indian birch	West Indies	0.35–0.40

Index No.	Family	Genus and species	Common name	Place of growth of material tested	D_d g/cm^3
896	*Canellaceae*	*Canella winterana*, Gaertn.	Canela	West Indies	1.10
897	*Celastraceae*	*Goupia glabra*, Aubl.	Cupiúba	Brazil	0.82–0.88
898		*Maytenus obtusifolia*, Mart.	Carne d'anta	Brazil	0.82
899	*Combretaceae*	*Terminalia* sp.	Naranjo	Guatemala	0.65–0.75
900		*Terminalia januarensis*, DC.	Araça	Brazil	0.77
901	*Cunoniaceae*	*Weinmannia trichosperma*, Cav.	Tenio	Chile	0.59
902	*Dilleniaceae*	*Curatella americana*, L.	Chaparro	Tropical America	0.77
903	*Eucryphiaceae*	*Eucryphia cordifolia*, Cav.	Ulmo	Chile	0.63
904	*Euphorbiaceae*	*Gymnanthes lucida*, Sw.	Aité	Cuba	1.00–1.20
905		*Hieronymia alchorneoides*, Fr. Allem.	Urucurana	Brazil	0.72
906		*Hippomane mancinella*, L.	Manzanillo	West Indies	0.68
907		*Hura crepitans*, L.	Javillo, possum wood	Tropical America	0.36–0.44
908	*Flacourtiaceae*	*Casearia praecox*, Gris.	Zapatero, W. Ind. boxwood	Venezuela	0.80–0.90
909		*Homalium* sp.	Angelino	Venezuela	0.75–0.85
910	*Guttiferae*	*Calophyllum calaba*, Jacq.	Santa María	Central America	0.68–0.74
911		*Mammea americana*, L.	Mamey	West Indies	0.90
912		*Platonia insignis*, Mart.	Pacouri	French Guiana	0.86
913		*Symphonia globulifera*, L. f.	Waikey, chewstick	British Honduras	0.65–0.70
914	*Humiriaceae*	*Humiria floribunda*, Mart.	Bastard bullet wood	British Guiana	0.85–0.92
915	*Juglandaceae*	*Juglans australis*, Gris.	Nogal	Argentina	0.56
916	*Lauraceae*	*Aniba panurensis*, Mez	Bois de rose	French Guiana	0.60–0.68
917		*Nectandra* sp.	Determa	British Guiana	0.65–0.70
918		*Nectandra* sp.	Embuia	Brazil	0.70–0.76
919		*Nectandra* sp.	Waibaima	British Guiana	1.15
920		*Nectandra rodioei*, Schomb.	Greenheart	British Guiana	1.06–1.23
921		*Persea lingue*, Nees	Lingue	Chile	0.55
922		*Phoebe ambigens*, Blake	Guambo	Honduras	0.50
923		*Phoebe porphyria*, (Gris.) Mez	Laurel negro	Argentina	0.50–0.80
924		*Silvia navalium*, Fr. Allem.	Tapinhoan	Brazil	0.86–1.00
925	*Lecythidaceae*	*Cariniana legalis*, (Mart.) Kuntze	Jequitibá	Brazil	0.50–0.70
926		*Cariniana pyriformis*, Miers	Albarco, Colombian mahogany	Colombia	0.65–0.70
927		*Chytroma jarana*, Huber	Jaraná	Brazil	0.98
928		*Eschweilera corrugata*, Miers	Manbarklak	Dutch Guiana	1.21
929		*Lecythis ollaria*, L.	Sapucaia	Brazil	0.95
930	*Leguminosae*	*Andira vermifuga*, Mart.	Angelim amargoso	Brazil	0.65
931		*Apuleia praecox*, Mart.	Iberá-peré	Argentina	0.80–0.95
932		*Bowdichia* sp.	Sucupira	Brazil	1.00
933		*Brya ebenus*, DC.	Granadillo	Cuba	1.20
934		*Caesalpinia echinata*, Lam.	Páo brasil, Pernambuco wood	Brazil	0.98–1.24
935		*Caesalpinia granadillo*, Pittier	Ebano, coffee wood, partridge	Venezuela	1.10–1.20
936		*Caesalpinia melanocarpa*, Gris.	Guayacan negro	Argentina	1.10–1.30
937		*Centrolobium* spp.	Araribá	Brazil	0.65–0.90
938		*Copaifera officinalis*, (L.) Willd.	Copaiba	Colombia	0.70
939		*Dalbergia* sp.	Honduras rosewood	British Honduras	0.93–1.08
940		*Dalbergia nigra*, Fr. Allem.	Jacarandá, Brazilian rosewood	Brazil	0.85
941		*Dalbergia retusa*, Hemsl.	Cocobolo	Central America	0.99–1.22
942		*Dialium divaricatum*, Vahl.	Jutahy peba	Brazil	0.90
943		*Dicorynia paraensis*, Benth.	Angélique	French Guiana	0.75–0.90
944		*Dimorphandra mora*, B. and H.	Mora	British Guiana	0.97–1.00
945		*Diplotropis* sp.	Zwarte kabbes	Dutch Guiana	1.15
946		*Dipteryx odorata*, Willd.	Tonca bean	British Guiana	1.20
947		*Enterolobium cyclocarpum*, (Jacq.) Gris.	Guanacaste	Central America	0.35–0.60
948		*Eperua falcata*, Aubl.	Wallaba	British Guiana	0.90
949		*Erythrina crista-galli*, L.	Ceibo	Argentina	0.25
950		*Eysenhardtia polystachia*, (Ort.) Sarg.	Palo dulce	Mexico	0.87
951		*Gleditschia amorphoides*, (Gris.) Taub.	Espina corona	Argentina	0.86–0.95
952		*Haematoxylon campechianum*, L.	Logwood	British Honduras	1.00
953		*Holocalyx balansae*, Mich.	Alecrin	Argentina	1.00
954		*Hymenaea courbaril*, L.	Courbaril, algarroba, locust	Tropical America	0.80–1.05
955		*Lysiloma sabicu*, Benth.	Sabicú	Cuba	0.77
956		*Melanoxylon brauna*, Schott.	Braúna	Brazil	1.00
957		*Myrocarpus frondosus*, Fr. Allem.	Cabreúva	Brazil	0.87–0.97
958		*Myroxylon toluiferum*, H. B. K.	Oleo vermelho	Brazil	1.00

Index No.	Family	Genus and species	Common name	Place of growth of material tested	D_d g/cm³
959		*Peltogyne paniculata*, Benth.	Purpleheart	British Guiana	1.00
960		*Peltophorum adnatum*, Gris.	Sabicú moruro	Cuba	1.02
961		*Peltophorum vogelianum*, Benth.	Caña fistola	Argentina	0.75–1.04
962		*Piptadenia* sp.	Curupay	Argentina	1.03
963		*Piptadenia rigida*, Benth.	Angico	Argentina	0.95
964		*Pithecolobium arboreum*, (L.) Urb.	Moruro	Cuba	0.74
965		*Pithecolobium racemiflorum*, Ducke	Bois serpent	French Guiana	1.15
966		*Pithecolobium vinhatico*, Record	Vinhatico de espinho	Brazil	0.60
967		*Plathymenia reticulata*, Benth.	Vinhatico castanho	Brazil	0.56–0.65
968		*Platycyamus regnellii*, Benth.	Pereira	Brazil	0.75
969		*Platymiscium polystachyum*, Benth.	Roble colorado	Venezuela	1.00
970		*Pterogyne nitens*, Tul.	Ibiráro	Argentina	0.76–1.09
971		*Swartzia tomentosa*, DC.	Wamara	British Guiana	1.05–1.28
972		*Sweetia panamensis*, Benth.	Billy Webb	British Honduras	1.00
973		*Tipuana speciosa*, Benth.	Tipa	Argentina	0.65
974		*Torresia cearensis*, Fr. Allem.	Umburana	Brazil	0.60
975		*Vouacapoua americana*, Aubl.	Acapú	Brazil	0.87–0.92
976		*Zollernia paraensis*, Huber	Páo santo	Brazil	1.30–1.33
977	*Magnoliaceae*	*Drimys winteri*, Forst.	Canelo	Chile	0.50
978	*Malpighiaceae*	*Byrsonima crassifolia*, H. B. K.	Nance	Mex., Centr. Amer.	0.70
979	*Malvaceae*	*Hibiscus elatus*, Sw.	Majagua	Cuba	0.65
980	*Melastomaceae*	*Mouriria pseudo-geminata*, Pittier	Pauji	Venezuela	0.82
981	*Meliaceae*	*Cabralea* spp.	Cancharana	Argentina	0.65
982		*Carapa guianensis*, Aubl.	Crabwood	British Guiana	0.60–0.75
983		*Cedrela* spp.	Cedro, cedar	Tropical America	0.37–0.70
984		*Guarea trichilioides*, L.	Muskwood	Jamaica	0.50–0.55
985		*Swietenia* spp.	Caoba, mahogany	Tropical America	0.45–0.85
986		*Trichilia alta*, Blake.	Pimenteira	Brazil	0.72
987	*Monimiaceae*	*Laurelia aromatica*, Juss.	Laurel	Chile	0.53
988	*Moraceae*	*Bagassa guianensis*, Aubl.	Tatajuba	Brazil	0.80
989		*Brosimopsis diandre*, Blake	Leiteira	Brazil	0.75
990		*Brosimum columbianum*, Blake	Guayamero	Colombia	0.81
991		*Brosimum paraense*, Huber	Satiné	French Guiana	0.98–1.05
992		*Cecropia adenopus*, Mart.	Ambay	Argentina	0.44
993		*Chlorophora tinctoria*, Gaud.	Mora, fustic	Tropical America	0.93–0.99
994		*Clarisia racemosa*, R. and P.	Oitiçica	Brazil	0.50–0.60
995		*Perebea* sp.	Kapiteinhout	Dutch Guiana	0.68
996		*Piratinera guianensis*, Aubl.	Letterhout, letterwood	Dutch Guiana	1.20–1.35
997	*Myristicaceae*	*Virola bicuhyba*, Warb.	Bicuiba	Brazil	0.63–0.72
998		*Virola sebifera*, Aubl.	Yayamadou	French Guiana	0.60
999	*Myrsinaceae*	*Rapanea laetevirens*, Mez.	Canelon	Argentina	0.55
1000	*Olacaceae*	*Minquartia guianensis*, Aubl.	Acaricuára	Brazil	0.98
1001	*Phytolaccaceae*	*Gallesia scorododendron*, Casar.	Páo d'alho	Brazil	0.58
1002	*Pinaceae*	*Araucaria brasiliana*, Lamb.	Pinheiro do Paraná	Brazil	0.50–0.60
1003	*Polygonaceae*	*Coccoloba uvifera*, L.	Uvero	Tropical America	0.98–1.10
1004		*Ruprechtia* sp.	Virarú	Argentina	0.66–0.76
1005	*Proteaceae*	*Roupala brasiliensis*, Kl.	Páo concha	Brazil	0.80–1.00
1006	*Rubiaceae*	*Calderonia salvadorensis*, Standl.	Brasil	Salvador	0.60
1007		*Calycophyllum candidissimum*, (Vahl.) DC.	Dágame, salamo, degame	W. I., Centr. Amer.	0.80
1008		*Calycophyllum multiflorum*, Gris.	Palo blanco	Argentina	0.92–1.03
1009		*Genipa americana*, L.	Jagua	Tropical America	0.73–0.84
1010		*Sickingia* sp.	Arariba	Brazil	0.88
1011	*Rutaceae*	*Amyris balsamifera*, L.	Amyris	Venezuela	0.99–1.10
1012		*Balfourodendron riedelianum*, Engl.	Guatambú	Argentina	0.75
1013		*Esenbeckia leiocarpa*, Engl.	Guarantán	Brazil	0.97–1.10
1014		*Euxylophora paraensis*, Huber	Páo amarello	Brazil	0.81
1015		*Zanthoxylum flavum*, Vahl.	West Indian satinwood	West Indies	0.90
1016	*Salicaceae*	*Salix humboldtiana*, Willd.	Sauce colorado	Argentina	0.44
1017	*Sapotaceae*	*Achras zapota*, L.	Nispero	Central America	1.09
1018		*Labourdonnaisia albescens*, Benth.	Almique	Cuba	0.97
1019		*Lucuma procera*, Mart.	Mucuri	Brazil	0.90
1020		*Mimusops* sp.	Massaranduba	Brazil	0.85–1.10
1021		*Mimusops globosa*, Gaertn.	Bullet wood	British Guiana	0.90–1.25

Index No.	Family	Genus and species	Common name	Place of growth of material tested	D_d g/cm³
1022		*Pradosia latescens*, (Vell.) Radlk.	Buranhem	Brazil	0.94
1023		*Sideroxylon mastichodendron*, Jacq.	Jocuma	Cuba	0.95–1.10
1024	*Simarubaceae*	*Quassia amara*, L.	Quassia	Surinam	0.50
1025		*Simaruba amara*, Aubl.	Marupá	Brazil	0.40–0.50
1026	*Sterculiaceae*	*Sterculia* sp.	Imbira quiaba	Brazil	0.25
1027	*Theaceae*	*Caryocar villosum*, Pers.	Piquiá	Brazil	0.81
1028	*Tiliaceae*	*Guazuma ulmifolia*, Lam.	Guacima	Tropical America	0.55
1029		*Luehea divaricata*, Mart.	Açoita-cavallo	Brazil	0.60
1030	*Ulmaceae*	*Celtis tala*, Gill.	Tala	Argentina	0.60–0.85
1031		*Phyllostylon brasiliensis*, Cap.	Baitoa, San Domingan boxwood	Dominican Repub.	0.95
1032	*Verbenaceae*	*Avicennia nitida*, Jacq.	Mangle prieto	Tropical America	0.95–1.10
1033		*Petitia domingensis*, Jacq.	Capá	West Indies	0.95
1034		*Vitex longeracemosa*, Pittier	Jocote de mico	Guatemala	0.70
1035	*Vochysiaceae*	*Qualea rosea*, Aubl.	Cèdre gris	French Guiana	0.65
1036		*Vochysia guatemalensis*, J. D. Smith	San Juan	Guatemala	0.42
1037	*Zygophyllaceae*	*Bulnesia arborea*, Engl.	Vera	Venezuela	1.10–1.25
1038		*Guaiacum officinale*, L.	Guayacan, lignum-vitae	West Indies	1.10–1.40

INDEX OF COMMON NAMES

The numbers in the following index refer to the Index Numbers in the preceding tables

DENSITY ARRANGEMENT

In the arrangement below, the lightest and heaviest woods are listed in the order (descending) of their bulk-densities in the air-dried condition. The bold-face numbers represent intervals on the density scale. The other numbers are the index numbers of the woods arranged in descending order of their densities. Bulk density = weight of air-dry piece divided by its bulk volume.

ARRANGEMENT PAR DENSITÉ

Dans l'arrangement ci-dessous les bois les plus légers et les plus lourds sont indiqués dans l'ordre (descendant) de leur densité apparente dans les conditions de séchage à l'air. Les nombres en caractères gras représentent les intervalles de l'échelle des densités. Les autres nombres sont les nombres index des bois disposés dans l'ordre descendant de leurs densités. Densité apparente = poids de la pièce séchée à l'air divisé par son volume apparent.

ANORDNUNG DER DICHTE

In der Anordnung unten sind die leichtesten und schwersten Hölzer in absteigender Reihe ihrer Dichten im Luft trockenem Zustande angegeben. Die hervorgehobenen Zahlen bezeichnen die Intervalle an der Dichteskala. Die anderen Zahlen sind die Indexnummern der angegebenen Hölzer in absteigender Reihe ihrer Dichten. Raumgewicht = Gewicht des Luft trockenen Stückes dividiert durch sein Volumen.

ORDINE SECONDO LE DENSITÀ

Nell'elenco che segue, i legni più leggeri e i più pesanti sono indicati nell'ordine decrescente delle loro densità nello stato di essiccamento all'aria. I numeri marcati in nero rappresentano gli intervalli nella scala delle densità. Gli altri numeri sono i numeri indice dei legni disposti in ordine decrescente delle loro densità. Densità apparente = peso del pezzo seccato all'aria diviso per il suo volume.

1.40: 1038, 996, 868, 976, 412, 936, 864, 136, 971, 522. **1.25**: 1037, 1021, 880, 512, 934, 920, 941, 928, 665, 552, 420. **1.20**: 946, 935, 933, 904, 523, 513, 501, 549, 731, 565, 554, 497. **1.15**: 965, 945, 919, 414, 638, 482, 555, 415, 540, 525, 587. **1.12**: 494, 207, 493, 536, 524, 1032, 1023, 1020, 1013, 1011, 1003, 896, 409. **1.09**: 1017, 970, 551, 537, 553, 939, 138, 498, 664, 570. **1.066**: 502, 234, 651, 530, 507, 991, 954, 571, 153, 583, 475. **1.04**: 961, 442, 1008, 962, 861, 228, 644, 477, 483. **1.02**: 960, 541, 491, 387, 484, 584, 509, 654. **1.00**: 1005, 972, 969, 959, 958, 956, 953, 952, 944, 932, 924, 871, 865, 357.

0.41: 883, 814, 466, 88, 55, 123, 272, 115, 271. **0.40**: 1025, 886, 878, 820, 815, 785, 218, 148, 154, 247. **0.38**: 842, 720, 321, 102, 983, 833, 816, 130, 253, 209, 91, 96. **0.36**: 907, 820, 213, 144, 947, 895, 887, 819, 721, 201, 129. **0.344**: 18, 467, 454, 844, 711, 702, 463. **0.25**: 1026, 949, 884. **0.189**: 674. **0.12**: 888. **0.10**: 885.

ARTIFICIAL LUMBERS

The data given below are intended to illustrate the order of magnitude of some of the properties found for samples of certain artificial materials manufactured in board form for special uses. Since the properties of such materials vary with the method of manufacture, and as such methods are constantly being improved, the actual characteristics of the manufactured product at a given time can be obtained only from the manufacturer.

Common or trade name	Composition and structure	Bulk density, g/cm³	Strength kg/cm² Tr. = transverse Ten. = tensile Cr. = crushing	Approximate thermal conductivity $k = 10^{-5}A$ g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ cf. p. 312 (4) A
Asbestos mill board	Asbestos + binder	1.0		29
Asbestos wood	Asbestos + cement	2.0	1050 Cr. (3) 246 Tr.	93
Asphalt roofing	Felt saturated with asphalt	0.9		24
Celotex*	Felted bagasse fibers	0.19 to 0.24	2.25 Tr. 26.2 Ten. (2)	10
Cork board	Cork, no binder	0.13		10
Cork board	Cork + bituminous binder	0.25		12
Insulite	Pressed wood pulp	0.19	1.62 Tr. 11.7 Ten. (2)	10 13
Lith board	Mineral wool, vegetable fibers + binder	0.2		
Sheet rock or plaster board	Gypsum + wood shavings		2.04 Tr. 12.3 Ten. (2)	
Wall board (gypsum)	Gypsum			80
Wall board	Stiff paper	0.7	13 Ten. (1)	17
Thermolath†	Vegetable fibers + waterproofing binder		11.9 Ten. (5) 1.14 Tr.	13 (5)

* Water absorptivity on 48 hr immersion = 10 vol. %.
† Water absorptivity on 48 hr immersion = 41 vol. %.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bird and Son, *O.* (2) Celotex Company, *Celotex.* (3) Johns-Manville Co., *Asbestos Wood.* (4) Van Dusen, *385*, **26**: 625: 20. (5) Waldorf Paper Products Co., *O.*

BUILDING STONES

D. W. Kessler

CONVERSION FACTORS

1 kg cm^{-2} = 14.22 lb. in.$^{-2}$ = 1.024 ton* ft.$^{-2}$

1 dyne cm^{-2} = 1.020 $\times$ 10^{-6} kg cm^{-2} = 1.450 $\times$ 10^{-5} lb. in.$^{-2}$ = 1.044 $\times$ 10^{-6} ton* ft.$^{-2}$

1 kg^{-1} cm^{2} = 1.020 $\times$ 10^{6} dyne^{-1} cm^{2} = 0.0703 lb.$^{-1}$ in.^{2} = 1.033 atm^{-1}

1 g cm^{-3} = 1000 kg m^{-3} = 62.4 lb. ft.$^{-3}$ = 0.843 ton* yd.$^{-3}$

1 joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ = 0.239 g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ = 9.48 $\times$ 10^{-4} BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$

per deg C = 0.556 per deg F.

* 1 ton = 2000 lb.

Compressive Strength

kg cm^{-2} $\times$ 10^{-3}

Example: For basalt from Limburg, 3200 kg per sq. cm (4).

Basalt, Av. Range—2.0 to 3.5

Near Linz a. R.	4.7	(6)
Limburg, Nassau	3.2	(4)
Ortenberg, Hesse	2.7	(4)
Lauterbach, Hesse	2.0	(4)

Phonolite

Rothweil, Baden	3.4	(12)
Aschaffenburg, L. Franconia	3.0	(4)

Porphyry, Av. Range—2.0 to 3.0

Quartz, Beutengrund, Silesia	3.2	(12)
Quartz, Reinsdorf, Silesia	2.2	(12)
Alpirsbach, Black Forest	2.0	(4)

Quartzite, Av. Range—1.0 to 2.0

Kugelberg, Alsace	3.2	(4)
Sierk near Metz	2.9	(4)
Pipestone, Minn	2.0	(45)
White Haven, Pa	1.1	(21)

Felsite

Rohrschweger, Alsace	2.9	(4)
Kerzheim, Alsace	2.0	(4)

Diabase

Ochenkopf, Bavaria	2.7	(4)
Hasselfelde, Harz Mts	2.1	(12)
Taylors Falls, Minn	1.8	(13)

Diorite, Av. Range—1.0 to 2.5

Freiburg, Baden	2.6	(4)
Aschaffenburg, L. Franconia	2.4	(4)
Boulder Canyon, Ariz	2.0	(21)
Quartz mica, Monson, Mass	1.1	(23)

Aplite

Hingham, Mass	2.5	(41)

Syenite, Av. Range—1.0 to 2.0

Fine grained, East St. Cloud, Minn	2.0	(13)
Porphyry, Pulaski Co., Ark	2.0	(34)
Red, Beaver Bay, Minn	1.9	(13)
Gray quartzose, East St. Cloud, Minn	1.9	(13)
Coarse, Watab, Minn	1.8	(13)
Fine grained, Sauk Rapids, Minn	1.5	(13)
Cape Ann, Mass	1.1	(13)
Weinheim, Baden	1.0	(4)

Serpentine, Av. Range—0.9 to 2.0

Hollysprings, Ga	2.0	(21)
Auburn, Calif	1.8	(38)
Roxbury, Vt	1.7	(21)
Einseidel, Bohemia	1.4	(15)
Zoblitz, Saxony	0.8	(16)

Granite, Av. Range—1.0 to 2.8

Quartz-monzonite, Westerly, R. I.	2.0	(41)
Muscovite, Stone Mountain, Ga	1.9	(32)
Hornblende, Mosquito Mt., Maine	1.6	(46)
Gneiss, Branford, Conn	1.6	(41)
Biotite, Milford, Mass	1.6	(41)
Biotite gneiss, Port Deposit, Md	1.6	(21)
Riebeckite-aegirite, Quincy, Mass	1.5	(20)
Hornblende, Rockport, Maine	1.4	(41)

Granite.—(*Continued*)

Coarse biotite, Stony Creek, Conn	1.1	(13)
Gneiss, Monson, Mass	1.1	(41)
Biotite, Aberdeen, Scotland	0.8	(13)

Gabbro

Rice Pt., Duluth, Minn	1.9	(13)
Randauthal, Hanover	1.0	(4)

Lava

Niedermendig, Rhine	1.9	(6)
Fremont Co., Colo	0.7	(18)

Marble, Av. Range—0.8 to 1.5

Hematitic dolomite, Swanton, Vt	1.9	(21)
Coarse dolomite, Pleasantville, N. Y	1.6	(13)
Carbonaceous, Isle LaMotte, Vt	1.5	(21)
Dolomite, South Dover, N. Y	1.4	(21)
Dolomite, Lee, Mass	1.4	(21)
Pink fossiliferous, Knoxville, Tenn	1.2	(21)
Saccharoidal calcite, Carrara, Italy	1.1	(15)
Saccharoidal calcite, Plattsburg, N. Y	1.0	(21)
Magnesian, Gouverneur, N. Y	1.0	(21)
Dolomite, Beaverdam, Md	0.9	(21)
Graphitic dolomite, Florence, Vt	0.9	(21)
Carbonaceous, Glens Falls, N. Y	0.8	(13)
Coarse calcite, Ball Ground, Ga	0.8	(21)
Saccharoidal calcite, Rutland, Vt	0.7	(21)
Actinolitic calcite, South Dorset, Vt	0.6	(21)

Dolomite, Av. Range—0.8 to 1.5

Compact, Lemont, Ill	1.9	(13)
Compact, Red Wing, Minn	1.6	(13)
Arenaceous, Kasota, Minn	0.9	(21)
Bituminous, Marblehead, Ohio	.8	(21)
Pitted, Jefferson City, Mo	.8	(21)
Vesicular, Stone City, Iowa	.4	(3)

Essexite

Mt. Johnson, Quebec	1.8	(1)

Granodiorite

Rocklin, Calif	1.5	(43)

Labradorite

Beaver Bay, Minn	1.5	(13)

Sandstone, Av. Range—0.5 to 1.5

Quartzitic, Potsdam, N. Y	1.5	(21)
Argillaceous, Warsaw, N. Y	1.4	(41)
Calcareous, Horst, Schleswig-Holstein	1.2	(12)
Calcareous, Craigleith, Scotland	0.9	(13)
Triassic, Hummelstown, Pa	.8	(21)
Triassic, Bellville, N. J	.8	(13)
Triassic, Portland, Conn	.7	(21)
Triassic, East Long Meadow, Mass	.7	(21)
Calcareous, Dorchester, N. B	.7	(13)
Feldspathic, Vitzenberg, Thuringia	.6	(12)
Calcareous, Warrensburg, Mo	.4	(8)
Feldspathic, Aquia Creek, Va	.4	(21)
Ferruginous, Chitwood, Ore	.4	(41)

Limestone, Av. Range—0.4 to 1.4

Argillaceous, St. Paul, Minn	1.4	(13)
Compact, Lias, France	1.4	(36)
Jurassic, Chatillon, France	1.4	(36)

Limestone.—(*Continued*)

Aluminous, Minneapolis, Minn	1.2	(13)
Compact, earthy, Cassville, Mo	0.9	(21)
Fine-grained oolite, Marshalltown, Iowa	.9	(3)
Vesicular, Mantorville, Minn	.7	(13)
Magnesian, Andalusia, Ill	.4	(35)
Oolitic, Bedford, Ind	.4	(21)
Jurassic, Isle of Portland	.3	(33)
Oolitic, Caen, Normandy	.25	(13)
Oolitic, Bath, England	.09	(29)

Conglomerate

Wilkesbarre, Pa	1.3	(18)
Königssee, Thuringia	1.2	(12)

Breccia (Volcanic)

Boulder Canyon, Ariz	1.0	(21)

Tufa

Lilliwaup, Wash	0.8	(31)

Slate

Pen Argyl, Pa	0.7	(11)

Trachyte

Köln, Rhine	0.7	(6)

Steatite

Arrington, Va	0.6	(21)

Tuff

Oregon	0.2	(21)
Grafenberg, Bavaria	0.1	(4)

Shearing Strength

The shearing values given in this table were determined by three types of apparatus, one of which appears to give results which are too low, due to the fact that bending stresses are produced. The values determined by authority No. 41 are probably low for this reason.

kg cm^{-2}

Marble, Av. Range—100 to 300

Hematitic dolomite, Swanton, Vt	450	(21)
Dolomitic, Lee, Mass	320	(21)
Impure calcite, Carthage, Mo	310	(21)
Graphitic calcite, Albertson, Vt	260	(21)
Pink fossiliferous, Knoxville, Tenn	250	(21)
Karstmarmor, Nabresina, Istria	110	(15)
Dolomitic, Tuckahoe, N. Y	105	(41)
Siliceous, Neubeuern, Bavaria	100	(4)
Saccharoidal calcite, Carrara, Italy	90	(15)
Fine-grained, Laas, Tyrol	60	(15)

Serpentine

Weisen, Tyrol	340	(15)
Hollysprings, Ga	320	(21)
Einsiedel, Bohemia	180	(15)

Granite, Av. Range—150 to 300

Muscovite, Stone Mountain, Ga	300	(21)
Biotite, Millbridge, Maine	200	(18)
Biotite, Milford, Mass	180	(41)
Hornblende, Rockport, Mass	170	(41)
Hornblende, Cape Ann, Mass	170	(22)
Muscovite-biotite, Troy, N. H	160	(41)
Fine-grained biotite, Schwarzwasser, Poland	140	(15)
Fine-grained biotite, Mauthausen, Austria	140	(4)
Biotite, Hauzenberg, Bavaria	130	(4)
Biotite, Baveno, Italy	90	(15)

Steatite

Arrington, Va	280	(21)

Slate

Calcareous mica, Pen Argyl, Pa	250	(21)
Siliceous mica, Monson, Maine	150	(27)

Limestone, Av. Range—100 to 200

Earthy dolomite, Quincy, Ill	210	(21)
Aluminous dolomite, Mantorville, Minn	200	(21)
Gray oolitic, Bedford, Ind	170	(10)
Buff oolitic, Bedford, Ind	150	(10)
Flinty, Buffalo, N. Y	150	(41)
Oolitic, Rockwood, Ala	150	(21)
Pure white oolitic, Kehlheim, Bavaria	30	(4)

Sandstone, Av. Range—50 to 150

Triassic, East Longmeadow, Mass	190	(21)
Fine-grained variegated, Murgtal, Baden	40	(4)
Argillaceous, Hochberg, Bavaria	30	(4)
Glauconitic, Ihrlerstein, Bavaria	20	(4)

Transverse Strength

Modulus of Rupture
kg cm^{-2}

Serpentine, Av. Range—100 to 350

Weisen, Tyrol	780	(15)
Hollysprings, Ga	340	(21)
Roxbury, Vt	310	(21)
Einsiedel, Bohemia	160	(15)
Auburn, Calif	90	(38)

Quartzite

White Haven, Pa	330	(21)

Marble, Av. Range—100 to 200

Hematitic dolomite, Swanton, Vt	300	(21)
Carbonaceous, Isle LaMotte, Vt	250	(21)
Fine-grained calcite, Laas, Tyrol	190	(15)
Pink fossiliferous, Knoxville, Tenn	180	(21)
Graphitic, Albertson, Vt	170	(21)
Saccharoidal calcite, Carrara, Italy	170	(15)
Karstmarmor, Nabresina, Istria	170	(15)
Fossiliferous, Plattsburg, N. Y	150	(21)
Dolomitic, Beaverdam, Md	150	(21)
Dolomitic, Lee, Mass	130	(21)
Coarse calcite, Ball Ground, Ga	110	(21)
Saccharoidal calcite, West Rutland, Vt	80	(21)

Granite, Av. Range—100 to 200

Fine-grained biotite, Mauthausen, Austria	230	(4)
Fine-grained biotite, Schwarzwasser, Poland	180	(15)
Hornblende, Cape Ann, Mass	170	(22)
Biotite, Millbridge, Maine	140	(18)
Biotite, Baveno, Italy	110	(15)
Biotite, Gefrees, Franconia	80	(4)

Sandstone, Av. Range—25 to 125

Flagstone, Lacyville, Pa	160	(21)
Quartzitic, Potsdam, N. Y	130	(21)
Triassic, Hummelstown, Pa	80	(21)
Feldspathic, McDermott, Ohio	80	(21)
Berea grit, Amherst, Ohio	50	(21)

Limestone, Av. Range—75 to 125

Arenaceous dolomite, Kasota, Minn	150	(21)
Compact earthy, Cassville, Mo	140	(21)
Flinty, Buffalo, N. Y	100	(41)
Pure white oolitic, Kehlheim, Bavaria	90	(4)
Oolitic, Bedford, Ind	80	(21)
Muschelkalk, Randersacker, Bavaria	70	(4)

Tensile Strength

kg cm^{-2}

Slate

Pen Argyl, Pa	250	(11)

Marble, Av. Range—30 to 90

Hematitic dolomite, Swanton, Vt	160	(21)
Carbonaceous, Isle LaMotte, Vt	90	(21)
Graphitic calcite, Albertson, Vt	90	(21)
Pink fossiliferous, Plattsburg, N. Y	90	(21)
Karstmarmor, Nabresina, Istria	90	(15)
Fine-grained, Laas, Tyrol	60	(15)
Coarse gr. calcite, Ball Ground, Ga	50	(21)
Dolomite, Parsberg, Bavaria	50	(4)
Saccharoidal calcite, Carrara, Italy	40	(15)
Dolomite, S. Dover, N. Y	30	(21)
Saccharoidal calcite, W. Rutland, Vt	30	(21)
Dolomite, Rehburg, Franconia	20	(4)

Serpentine

Roxbury, Vt	110	(21)
Einsiedel, Bohemia	100	(15)
Hollysprings, Ga	100	(21)
Weisen, Tyrol	60	(15)

Limestone, Av. Range—30 to 60

Compact earthy, Cassville, Mo	90	(21)
Compact earthy, Phenix, Mo	80	(21)
Arenaceous dolomite, Kasota, Minn	50	(21)
Buff oolitic, Bedford, Ind	30	(10)
Oolitic, Rockwood, Ala	30	(21)
Aluminous dolomite, Mantorville, Minn	20	(21)

Granite, Av. Range—30 to 50

Gneissoid, St. Gothard Tunnel	40	(4)
Biotite, Hausenberg, Bavaria	40	(4)
Fine-grained, Schwarzwasser, Poland	40	(15)
Biotite, Baveno, Italy	40	(15)

Sandstone, Av. Range—10 to 30

Feldspathic, McDermott, Ohio	40	(21)
Asphaltic, Liberal, Mo	20	(8)
Fine-grained variegated, Murgtal, Baden	20	(4)
Triassic, E. Longmeadow, Mass	20	(21)
Variegated, Kronach, Bavaria	10	(4)
Argillaceous, Hochberg, Bavaria	10	(4)
Glauconitic, Ihrlerstein Bavaria	10	(4)

Trachyte

Spitzberg, Bohemia	40	(15)

Resistance to Abrasion ("Hardness") (19)

The hardness values were determined by subjecting cylindrical specimens 2.5 cm in diameter to the abrasive action of crushed and graded quartz which is fed upon a revolving steel disc. The coefficient of hardness equals $20 - (\frac{1}{3})w$, where w is the weight of specimen worn away by 1000 revolutions of the disc.

Rhyolite, Av. Range—18 to 20

Adams Co., Pa	$\nless 20$
Milton, Calif	$\nless 20$
Boise, Idaho	15

Basalt, Av. Range—17 to 19

Nephelite, Austin, Texas	19
Olivine, Cliffs, Wash	18

Diabase, Av. Range—17 to 19

Upper Nyack, N. Y	19
Ansonia, Conn	18

Quartzite, Av. Range—16 to 19

Roanoke, Va	19
Greenbank, Del	18

Gabbro, Av. Range—16 to 18

St. Peters, Pa	19
York Haven, Pa	18

Trachyte

Colorado Springs, Colo	19

Chert

Chockie, Okla	19
Provo, Utah	17

Amphibolite

Wilmington, Del	19

Granite, Av. Range—17 to 19

Biotite, Vinal Haven, Maine	19
Biotite, Barre, Vt	19
Hornblende, Beverly, Mass	19
Aplitic, Richmond, Va	18
Biotite, Mt. Airy, N. C	18
Quartz monzonite, Milford, N. H	18

Slate, Av. Range—12 to 18

Clay, Berks Co., Pa	19
Siliceous, Montgomery Co., Pa	18
Calcareous, Waynesboro, Va	12
Heber Springs, Ark	9

Diorite, Av. Range—16 to 19

Bakersfield, Calif	19
Granite Falls, Wash	18
Glen Mills, Pa	17

Gneiss, Av. Range—16 to 19

Hornblende, Middle Valley, N. J	19
Sericite, Atlanta, Ga	18
Biotite, Hanover, N. H	18
Diorite, Derwood, Md	18
Pyroxene, Little Falls, N. Y	17

Schist, Av. Range—15 to 18

Quartz hornblende, Havre de Grace, Md	19
Sericite, Atlanta, Ga	18
Quartzite, Haverhill, N. H	18
Muscovite, Charlottesville, Va	17

Andesite

Elbe, Wash	18

Syenite

Vera Cruz, Pa	18
Charlottesville, Va	17

Sandstone, Av. Range—12 to 18

Argillaceous, Culpeper, Va	18
Ferruginous, Manassas, Va	18
Calcareous, Huntington, W. Va	16
Argillaceous, Salford, Pa	16
Chloritic, Warren, R. I	15
Ferruginous, Shreveport, La	14
Feldspathic, Parkersburg, W. Va	12
Bituminous, Provo, Utah	6
Ferruginous, Marshall, Texas	3

Serpentine, Av. Range—12 to 16

Rockville, Md	18
Blue Mountain, Pa	15
Newark, Calif	12

Limestone, Av. Range—12 to 17

Siliceous, Coyote, Calif	17
Carbonaceous, Petersburg, Ind	17
Fossiliferous, East Smithfield, Pa	16
Dolomitic, Huntington, W. Va	15
Crystalline, New Decatur, Ala	15
Dolomite, Joliet, Ill	14
Travertine, Damascus, Va	12
Argillaceous, Pontoosuc, Ill	9
Bituminous, Ravia, Okla	3

Marble, Av. Range—10 to 16

Hematitic dolomite, Burlington, Vt	17
Dolomitic, Port Kennedy, Pa	15
Graphitic calcite, Regal, N. C	14
Calcite, Ball Ground, Ga	11
Siliceous, Texas, Md	8

Tuff

Andesite, Petaluma, Calif	5

Steatite

New London, N. C	4

Impact Hardness ("Toughness") (19)

The toughness values were determined by subjecting cylindrical specimens 2.5 cm high by 2.5 cm diameter to the impact produced by the fall of a 2 kg hammer upon a steel plunger, the lower end of which is spherical and rests on the test piece. The weight is first dropped from a height of 1 cm which is increased 1 cm for each blow until the specimen breaks. The toughness is recorded as the height of the last hammer fall.

Slate, Av. Range—10 to 25

Clay, Berks Co., Pa	56
Indurated, Green Lane, Pa	40
Micaceous, Green Lane, Pa	17
Heber Springs, Ark	16
Siliceous, Montgomery Co., Pa	11
Calcareous, Waynesboro, Va	10

Sandstone, Av. Range—5 to 20

Ferruginous, Manassas, Va	47
Feldspathic, Little Rock, Ark	37
Ferruginous, Berks Co., Pa	35
Argillaceous, Culpeper, Va	24
Chloritic, Warren, R. I	24
Calcareous, Monroe, N. Y	19
Argillaceous, Hughesville, Pa	13

Sandstone.—(*Continued*)

Calcareous, Harrisburg, Pa	13
Ferruginous, Shreveport, La	8
Conglomerate, Sullivan Co., Pa	8
Calcareous, Huntington, W. Va	7
Feldspathic, Parkersburg, W. Va	6
Argillaceous, Salford, Pa	6
Bituminous, Provo, Utah	6
Ferruginous, Marshall, Texas	3

Rhyolite, Av. Range—5 to 25

Adams Co., Pa	42
Milton, Calif	20
Boise, Idaho	6

Diorite, Av. Range—8 to 25

Bakersfield, Calif	36
Granite Falls, Wash	17
Glen Mills, Pa	12

Schist, Av. Range—8 to 25

Chlorite epidote, Haw River, N. C	34
Quartz hornblende, Havre de Grace, Md	19
Sericite, Atlanta, Ga	10
Quartzite, Haverhill, N. H	10
Muscovite, Charlottesville, Va	7
Biotite, Leominster, Mass	6

Diabase, Av. Range—5 to 30

Ansonia, Conn	32
Upper Nyack, N. Y	23

Granite, Av. Range—5 to 18

Hornblende, Beverly, Mass	31
Coarse biotite, Vinal Haven, Maine	12
Biotite, Barre, Vt	9
Quartz monzonite, Milford, N. H	8
Aplitic, Richmond, Va	8
Biotite, Mt. Airy, N. C	7
Muscovite, Stone Mountain, Ga	7

Quartzite, Av. Range—5 to 25

Greenbank, Del	30
Courtland, Minn	22
Rockville, Pa	20
Roanoke, Va	14

Basalt, Av. Range—5 to 30

Hoquiam, Wash	27
Nephelite, Austin, Texas	24
Olivine, Cliffs, Wash	18
Lind, Wash	14

Gneiss, Av. Range—5 to 15

Hornblende, Middle Valley, N. J	26
Pyroxene, Little Falls, N. Y	18
Plagioclase, Clinton Co., N. Y	10
Sericite, Atlanta, Ga	8
Chlorite, East Providence, R. I	8
Diorite, Derwood, Md	7
Biotite, Hanover, N. H	6

Chert

Chockie, Okla	25
Provo, Utah	6

Limestone, Av. Range—5 to 15

Dolomite, Springfield, Mo	21
Carbonaceous, Petersburg, Ind	20
Dolomitic, Washington, Pa	14
Fossiliferous, East Smithfield, Pa	10
Siliceous, Coyote, Calif	8
Dolomitic, Huntington, W. Va	8
Dolomite, Joliet, Ill	8
Crystalline, New Decatur, Ala	7
Cherty, Akron, N. Y	7
Bituminous, Ravia, Okla	6
Shell, Fort Myers, Fla	6
Argillaceous, Pontoosuc, Ill	4
Travertine, Damascus, Va	4

Trachyte

Colorado Springs, Colo	21

Tuff

Basalt, Rio Piedras, Porto Rico	20
Andesite, Petaluma, Calif	5

Amphibolite

Wilmington, Del	18

Marble, Av. Range—2 to 10

Hematitic dolomite, Burlington, Vt	18
Dolomitic, Port Kennedy, Pa	5
Graphitic calcite, Regal, N. C	4
Siliceous, Texas, Md	3
Calcite, Ball Ground, Ga	2

Serpentine, Av. Range—8 to 15

Rockville, Md	17
Blue Mountain, Pa	11
Newark, Calif	6

Gabbro, Av. Range—8 to 22

St. Peters, Pa	17
York Haven, Pa	15

Syenite, Av. Range—10 to 15

Vera Cruz, Pa	16
Spartanburg, S. C	10
Charlottesville, Va	10

Andesite

Augite, Elbe, Wash	9

Steatite

New London, N. C	6

Elasticity

Young's Modulus

(Dynes cm^{-2}) $\times 10^{-11}$

Example: For oolitic Bedford limestone, 180,000,000,000 dyne per sq. cm (10).

Schist

Chlorite, Chichibu, Japan	12	(24)

Limestone, Av. Range—3 to 6

Schalstein, Rickuchyu, Japan	11	(24)
Fossiliferous, Montreal, Canada	6.4	(1)
Impure calcite, Carthage, Mo	5.4	(21)
Arenaceous dolomite, Kasota, Minn	4.0	(21)
Oolitic, Rockwood, Ala	3.8	(21)
Aluminous, Mantorville, Minn	3.0	(21)

Limestone.—(*Continued*)

Oolitic, Russelville, Ala	2.9	(21)
Oolitic, Bedford, Ind	1.8	(10)

Gabbro

New Glasgow, Quebec	11	(1)

Marble, Av. Range—5 to 7

Carbonaceous, Isle LaMotte, Vt	10	(21)
Belgian black, Dinant, Belgium	7.2	(1)
Hematitic dolomite, Swanton, Vt	7.0	(21)
Graphitic calcite, Albertson, Vt	6.3	(21)
Fossiliferous, Knoxville, Tenn	6.2	(1)
Saccharoidal calcite, Carrara, Italy	5.5	(1)
Saccharoidal calcite, Rutland, Vt	5.2	(1)
Pink fossiliferous, Plattsburg, N. Y	5.0	(21)

Diabase

Sudbury, Ontario	9.5	(1)

Slate, Av. Range—6 to 9

Siliceous, Granville, N. Y	9.0	(21)
Sandy, Rickuchyu, Japan	8.2	(24)
Calcareous, Pen Argyl, Pa	6.2	(11)
Clay, Tanba, Japan	3.2	(24)

Anorthosite

New Glasgow, Quebec	8.2	(1)

Essexite

Mt. Johnson, Quebec	6.7	(1)

Serpentine (Peridotite)

Kuzi, Japan	6.6	(24)
Roxbury, Vt	5.8	(21)
Hollysprings, Ga	3.3	(21)

Syenite (Nephelite)

Montreal, Canada	6.3	(1)

Granite, Av. Range—4 to 6

Biotite, Peterhead, Scotland	5.7	(1)
Biotite, Lake Lilly, N. B	5.6	(1)
Light gray hornblende, Rockport, Mass	5.5	(41)
Quartz monzonite, Westerly, R. I	5.1	(1)
Riebeckite aegirite, Quincy, Mass	5.0	(1)
Biotite, Aberdeen, Scotland	5.0	(5)
Biotite, Baveno, Italy	4.7	(1)
Biotite muscovite, Sanstead, Canada	3.9	(1)

Steatite

Arrington, Va	3.9	(21)

Dolomite

Yellow, Anston, Yorkshire	3.4	(5)
Siliceous, Mansfield, Nottingham	2.3	(5)

Rhyolite

Izu, Japan	2.5	(24)
Kozuke, Japan	1.9	(24)

Tuff

Rhyolite, Iyo, Japan	2.1	(24)
Rhyolite, Mikawa, Japan	1.8	(24)
Andesite, Echizen, Japan	1.3	(24)
Rhyolite, Iwashiro, Japan	1.1	(24)
Izu, Japan	0.67	(24)
Rhyolite, Tochigi, Japan	0.20	(24)

Sandstone

Feldspathic, Cleveland, Ohio	1.6	(1)
Triassic, East Longmeadow, Mass	1.6	(21)
Bluestone, McDermott, Ohio	1.3	(21)

Bulk Density

$g\ cm^{-3}$

Basalt, Nephelite

Austin, Texas	3.19	(19)
Debus, Bohemia	3.06	(12)
Lind, Wash	2.94	(19)

Gabbro

York Haven, Pa	3.04	(19)
Rice Pt., Duluth, Minn	2.79	(9)

Gneiss, Av. Range—2.7 to 2.95

Hornblende, Port Deposit, Md	3.04	(19)
Diorite, Amherst Co., Va	2.94	(19)
Pyroxene, Little Falls, N. Y	2.90	(19)
Chlorite, E. Providence, R. I	2.80	(19)
Sericite, Havre de Grace, Md	2.69	(19)
Biotite, Ansonia, Conn	2.69	(19)
Chloritic sericite, Potomac, Md	2.69	(19)

Breccia

Basalt, Culpeper, Va	3.00	(19)
Volcanic, Boulder Canyon, Ariz	2.46	(21)
Rhyolite, Silver Cliff, Calif	2.14	(19)

Diabase

Taylors Falls, Minn	3.00	(13)

Schist, Av. Range—2.7 to 2.95

Chlorite, Chichibo, Japan	2.97	(24)
Talc, Prov. Awa, Japan	2.94	(40)
Chlorite epidote, Haw River, N. C	2.80	(19)
Hornblende, Port Deposit, Md	2.73	(19)
Biotite, Atlanta, Ga	2.72	(19)
Sericite, Leominster, Mass	2.69	(19)
Quartzite, San Pedro, Calif	2.64	(19)

Steatite

Arrington, Va	2.97	(21)
New London, N. C	2.85	(19)

Marble, Av. Range—2.7 to 2.85

Coarse-grained dolomite, Texas, Md	2.86	(28)
Dolomitic, Lee, Mass	2.86	(21)
Small crystal dolomite, South Dover, N. Y	2.86	(21)
Hematitic dolomite, Swanton, Vt	2.83	(21)
Carbonaceous, Isle LaMotte, Vt	2.76	(21)
Magnesian, Gouverneur, N. Y	2.74	(21)
Coarse-grained calcite, Marblehill, Ga	2.72	(21)
Saccharoidal calcite, Rutland, Vt	2.71	(21)
Graphitic calcite, Albertson, Vt	2.71	(21)
Carbonaceous, Glens Falls, N. Y	2.70	(13)
Red and white, Cerfontaine, Belgium	2.21	(2)

Serpentine—Av. Range—2.7 to 2.8

Hollysprings, Ga	2.84	(21)
Peridotite, Kuzi, Japan	2.82	(24)
Roxbury, Vt	2.80	(21)
Rockville, Md	2.69	(19)
Auburn, Calif	2.54	(38)

Limestone, Av. Range—2.3 to 2.7

Dolomite, Springfield, Mass	2.80	(19)
Compact dolomite, Red Wing, Minn	2.75	(9)
Argillaceous, Clarksburg, W. Va	2.75	(19)
Argillaceous, St. Paul, Minn	2.71	(9)
Aluminous, Minneapolis, Minn	2.71	(9)
Travertine, Damascus, Va	2.69	(19)
Compact earthy, Cassville, Mo	2.66	(21)
Vesicular, Mantorville, Minn	2.65	(21)
Siliceous, Petersburg, Ind	2.64	(19)
Lithographic, Solenhofen, Bavaria	2.60	(7)
Arenaceous dolomite, Kasota, Minn	2.57	(21)
Pitted dolomite, Jefferson City, Mo	2.55	(8)
Compact, hard, Lias, France	2.40	(36)
Bituminous, Marblehead, Ohio	2.40	(13)
Magnesian, impure, Andalusia, Ill	2.34	(35)
Gray oolitic, Bedford, Ind	2.32	(21)
Buff oolitic, Bedford, Ind	2.28	(21)
Oolitic, Caen, Normandy	1.90	(13)

Slate, Av. Range—2.7 to 2.8

Calcareous, Pen Argyl, Pa	2.80	(11)
Siliceous, Granville, N. Y	2.76	(11)
Sandy, Rikuchyu, Japan	2.64	(24)
Clay, Mikawa, Japan	2.44	(24)

Diorite

Boulder Canyon, Ariz	2.77	(21)

Anorthosite

Au Sable Forks, N. Y	2.75	(26)

Quartzite

Pipestone, Minn	2.73	(45)
White Haven, Pa	2.67	(21)
E. Sioux Falls, S. D	2.64	(21)

Syenite, Av. Range—2.6 to 2.7

Coarse light-colored, Watab, Minn	2.73	(9)
Fine-grained gray, Sauk Rapids, Minn	2.71	(9)
Fine-grained gray, East St. Cloud, Minn	2.70	(9)
Porphyry, Pulaski Co., Ark	2.69	(34)
Fine-grained red, Beaver Bay, Minn	2.65	(9)
Red, East St. Cloud, Minn	2.63	(9)
Gray quartzose, East St. Cloud, Minn	2.63	(9)

Granite, Av. Range—2.65 to 2.7

Coarse biotite, Vinal Haven, Maine	2.72	(13)
Riebeckite-aegirite, Quincy, Mass	2.70	(13)
Biotite gneiss, Port Deposit, Md	2.68	(21)
Anorthosite, Au Sable Forks, N. Y	2.65	(13)
Coarse biotite, Vinal Haven, Maine	2.65	(21)
Coarse biotite, Stony Creek, Conn	2.65	(13)
Muscovite, Stone Mountain, Ga	2.63	(21)
Hornblende, Bay of Fundy, N. B	2.60	(13)

Chert

Provo, Utah	2.69	(19)

Felsite

Beaver Bay, Minn	2.69	(9)

Sandstone, Av. Range—2.2 to 2.6

Chloritic, Warren, R. I	2.69	(19)
Feldspathic, Portsmouth, R. I	2.68	(19)
Brown Potsdam, Fond du Lac, Wis	2.52	(9)
Ferruginous, Manassas, Va	2.52	(19)

Sandstone.—*(Continued)*

Argillaceous, Logan, Ohio	2.50	(19)
Triassic, Belleville, N. J	2.26	(13)
Brownstone, Edinburgh, Scotland	2.26	(13)
Calcareous, Warrensburg, Mo	2.21	(8)
Triassic, East Longmeadow, Mass	2.17	(21)

Rhyolite

Dunbarton, Calif	2.69	(19)
Kozuke, Japan	2.46	(24)
Izu, Japan	2.10	(24)

Tuff

Rhyolite, Lake Shore, Calif	2.63	(19)
Rhyolite, Iyo, Japan	2.33	(24)
Basalt, Holcomb, Wash	2.29	(19)
Rhyolite, Douglas Co., Colo	2.19	(25)
Andesite, Petaluma, Calif	1.84	(19)
Rhyolite, Tochigi, Japan	1.37	(24)

Andesite

Echizen, Japan	2.42	(24)

Porosity

Per cent of pore space

Diabase

Hohenberg, Bavaria	0.2	(2)
Hohenberg, Bavaria, green	0.5	(12)
Wiesbaden, Germany	1.2	(12)

Granite, Av. Range—0.5 to 1.5%

Biotite, Peterhead, Scotland	0.3	(2)
Biotite, Lysekil, Sweden	0.8	(12)
Biotite, Karlskrana, Sweden	1.0	(12)
Biotite, Malmö, Sweden	1.3	(12)
Hornblende, Pontresina, Switzerland	2.6	(39)

Basalt

Lichtenau, Westphalia, blue	0.4	(12)
Debus, Bohemia	0.5	(12)

Marble, Av. Range—0.5 to 1.0%

Graphitic calcite, Albertson, Vt	0.4	(21)
Saccharoidal calcite, Rutland, Vt	0.4	(21)
Carbonaceous, Isle LaMotte, Vt	0.5	(21)
Hematitic dolomite, Swanton, Vt	0.5	(21)
Dolomitic, Beaverdam, Md	0.6	(21)
Dolomitic, Lee, Mass	0.7	(21)
Black, Dinant, Belgium	0.7	(2)
Fossiliferous, Meadow, Tenn	0.8	(21)
Saccharoidal calcite, Carrara, Italy	0.8	(2)
Red and white, Cerfontaine, Belgium	0.9	(2)
Breccia, Besazio, Switzerland	1.5	(39)
Magnesian, Ollon, Switzerland	1.8	(39)

Limestone, Av. Range—3.0 to 15%

Glauconitic, Sachseln, Switzerland	1.0	(39)
Compact, earthy, Cassville, Mo	2.0	(21)
Oolitic, St. Ursanne, Switzerland	4.8	(39)
Pitted dolomite, Jefferson City, Mo	8.3	(8)
Compact fossiliferous, Derbyshire	8.4	(2)
Oolitic, Bowling Green, Ky	16.0	(21)
Oolitic, Bedford, Ind	16.0	(21)
Schaumkalk, La Coudre, Switzerland	17.0	(39)
Bath oolite, Monks Park, Somerset	20.0	(2)

Porphyry

Quartz, Beutengrund, Silesia	1.4	(12)

Quartzite

White, E. Sioux Falls, S. Dak	1.5	(21)
Red, White Haven, Pa	1.6	(21)
Pink, Ashby-de-la-Zouch, England	2.9	(2)

Sandstone, Av. Range—5 to 20%

Calcareous, Beckenried, Switzerland	1.9	(39)
Graywacke, Huttensteinach, S. Coburg-Gotha.	3.7	(12)
Flagstone, Lacyville, Pa	5.6	(21)
Quartzitic, Potsdam, N. Y	6.7	(21)
Yellow grit, Leeds, England	12.0	(2)
Calcareous, Hummelstown, Pa	13.0	(21)
Brownstone, Portland, Conn	13.0	(21)
Calcareous, Mansfield, Nottingham	15.0	(2)
Calcareous, Warrensburg, Mo	17.0	(8)
Feldspathic, McDermott, Ohio	17.0	(21)
Triassic, East Longmeadow, Mass	19.0	(21)
Berea grit, Amherst, Ohio	20.0	(21)
Coarse grit, Glenmont, Ohio	22.0	(21)

Gneiss

Two mica, Cresciano, Switzerland	2.5	(39)
Biotite, Castaneda, Switzerland	3.7	(39)
Muscovite, Osogna, Switzerland	4.4	(39)

Gabbro

Randauthal, Hanover	3.0	(12)

Breccia

Quartz, Mels, Switzerland	3.7	(39)

Diorite

Quartz, Pontresina, Switzerland	4.3	(39)

Serpentine

Peridotite, Hospenthal, Switzerland	6.0	(39)

Tuff

Calcareous, Oberdorf, Switzerland	17.0	(39)

Compressibility

$$\frac{1}{v}\frac{dv}{dP},\ \text{kg}^{-1} \times 10^{-6}$$

Example: For granite, the compressibility at a pressure of 2 000 kg cm^{-2} is 0.000 0021 or 0.000 21% per kg.

Granite	at 2 000 kg per sq. cm	1.1	(44)
	at 10 000 kg per sq. cm	1.8	(44)
Basalt	at 2 000 kg per sq. cm	1.8	(44)
	at 10 000 kg per sq. cm	1.5	(44)
Marble	at 2 000 kg per sq. cm	1.4	(44)
	at 10 000 kg per sq. cm	1.4	(44)
Limestone 0 to 12 000 kg per sq. cm			
Lithographic	at 75°C	1.4	(7)
	at 30°C	1.3	(7)
Diabase	at 2 000 kg per sq. cm	1.2	(44)
	at 10 000 kg per sq. cm	1.2	(44)

Thermal Expansion

$$\frac{1}{l}\frac{\Delta l}{\Delta t},\ \text{deg}^{-1}\ \text{C} \times 10^{-6}$$

Example: For Bedford limestone between 25 and 100°, 0.000 009 or 0.000 9% per °C.

Limestone

Semi-crystalline, Somersetshire, England	20° to 100°	22	(2)
Semi-crystalline, Somersetshire, England	100 to 200	26	(2)
Semi-crystalline, Somersetshire, England	200 to 300	27	(2)
Oolitic, Bedford, Ind	25 to 100	9	(37)
Oolitic, Bedford, Ind	100 to 200	17	(37)

Limestone.—(*Continued*)

Oolitic, Bedford, Ind	200 to 300	22	(37)
Dense fossiliferous, Derbyshire, England	20 to 100	9	(2)
Dense fossiliferous, Derbyshire, England	100 to 200	16	(2)
Derbyshire, England	200 to 300	21	(2)
Mt. Vernon, Ky	0 to 100	8.3	(41)
Dense fossiliferous, Mt. Vernon, Ky	100 to 200	8.8	(41)
Oolitic, Bath, England	20 to 100	4.2	(2)
Oolitic, Bath, England	100 to 200	9.6	(2)
Oolitic, Bath, England	200 to 300	19	(2)

Marble

Blue calcite, Rutland, Vt	25 to 100	16	(37)
Blue calcite, Rutland, Vt	100 to 200	25	(37)
Blue calcite, Rutland, Vt	200 to 300	29	(37)
White magnesian calcite, Pittsford, Vt	25 to 100	14	(37)
White magnesian calcite, Pittsford, Vt	100 to 200	23	(37)
White magnesian calcite, Pittsford, Vt	200 to 300	25	(37)
Gray fossiliferous, Knoxville, Tenn	25 to 100	10	(37)
Gray fossiliferous, Knoxville, Tenn	100 to 200	22	(37)
Gray fossiliferous, Knoxville, Tenn	200 to 300	27	(37)
Fine-grained, Couillet, Belgium	20 to 100	9.2	(2)
Fine-grained, Couillet, Belgium	100 to 200	19	(2)
Fine-grained, Couillet, Belgium	200 to 300	19	(2)
Saccharoidal calcite, Carrara, Italy	20 to 100	8.8	(2)
Saccharoidal calcite, Carrara, Italy	100 to 200	18	(2)
Saccharoidal calcite, Carrara, Italy	200 to 300	24	(2)
Dolomitic, Lee, Mass	0 to 100	8.1	(41)
Dolomitic, Lee, Mass	100 to 200	13	(41)
Dense black, Dinant, Belgium	20 to 100	4.9	(2)
Dense black, Dinant, Belgium	100 to 200	10	(2)
Dense black, Dinant, Belgium	200 to 300	14	(2)
Coarse calcite, Marble Hill, Ga	0 to 100	3.6	(41)
Coarse calcite, Marble Hill, Ga	100 to 200	19	(41)

Quartzite

Pink, Ashby-de-la-Zouch, England	20 to 100	16	(2)
Pink, Ashby-de-la-Zouch, England	100 to 200	20	(2)
Pink, Ashby-de-la-Zouch, England	200 to 300	20	(2)

Sandstone

Yellow grit, Leeds, England	20 to 100	12	(2)
Yellow grit, Leeds, England	100 to 200	16	(2)
Yellow grit, Leeds, England	200 to 300	19	(2)
Calcareous, Nottingham, England	20 to 100	10	(2)
Calcareous, Nottingham, England	100 to 200	15	(2)
Calcareous, Nottingham, England	200 to 300	19	(2)
Triassic, Kibbe, Mass	0 to 100	10	(41)
Triassic, Kibbe, Mass	100 to 200	14	(41)
Triassic, Seneca Creek, Md	0 to 100	5	(41)

Slate

Mica slate, Hydeville, Vt	0 to 100	12	(14)
Mica slate, Monson, Maine	0 to 100	9.4	(41)
Mica slate, Monson, Maine	100 to 200	9.7	(41)

Granite

Quartz monzonite, Westerly, R. I	20 to 100	9	(42)
Quartz monzonite, Westerly, R. I	100 to 200	14	(42)
Quartz monzonite, Westerly, R. I	200 to 300	20	(42)
Biotite, Milford, Mass	0 to 100	7.6	(41)
Biotite, Milford, Mass	100 to 200	13	(41)
Gneissoid, Branford, Conn	0 to 100	7.2	(41)
Gneissoid, Branford, Conn	100 to 200	17	(41)
Muscovite-biotite, Troy, N. H	0 to 100	6.1	(41)
Muscovite-biotite, Troy, N. H	100 to 200	12	(41)

Diabase

	20 to 100	6.3	(42)
	100 to 200	9	(42)
	200 to 300	12	(42)

Specific Heat

The heat capacity of building stones, irrespective of type, varies within the rather narrow limits of 0.7–0.95 joule per g or 0.18–0.23 cal, per g or BTU per lb. for the dry stone. An occasional higher value, such as 0.28 cal per g for a serpentine from Cornwall, Eng., has been reported (17, 40).

Thermal Conductivity

Joules $cm^{-2}\ sec^{-1}$ (°C, cm^{-1})
Room temperatures

Quartzite

Variegated, Prov. Bungo, Japan	0.054	(40)
Prov. Hizen, Japan	.031	(40)

Gneiss

Osogna, Turin	.034	(48)

Schist

Talc, Prov. Awa, Japan	.033	(40)
Granite, Simplon Tunnel	.027†§	(48)
Epidote, Prov. Awa, Japan	.018	(40)
Piedmontite, Prov. Awa, Japan	.009	(40)

Marble, Av. Range—0.02 to 0.03 (*See also infra*)

Black, Golzines, Belgium	.032	(30)
Dense fossiliferous, Knoxville, Tenn	.032	(30)
Saccharoidal, Japan	.030	(47)
Fine-grained yellow, Monte Arenti, Italy	.028	(30)
Breccia, Seravezza, Italy	.028	(30)
Carbonaceous, Isle LaMotte, Vt	.028	(30)
Yellow marble, Estremoz, Portugal	.028	(30)
Red marble, Devonshire, England	.023	(17)
Onyx, Mexico	.023	(30)
Green marble, Ireland	.023	(17)
Saccharoidal calcite, Carrara, Italy	.021	(30)
Vermont	.021	(30)

Serpentine

Prov. Hitachi, Japan	.030	(40)
Red, Cornwall, England	.020	(17)

Gabbro

Hornblende, Prov. Chikuzen, Japan	.030	(40)
Hornblende, Prov. Awadi, Japan	.018	(40)

Sandstone, Av. Range—0.025 to 0.03 (*See also* p. 315)

Hard grit, Linton, England	.029*	(17)
Hard grit, Linton, England	.026†	(17)
Flagstone, Loch Rannoch	.027‡	(17)
Flagstone, Loch Rannoch	.021§	(17)
Feldspathic, Bristol, England	.027	(17)

* Stone wet. ‡ Perpendicular to cleavage.
† Stone dry. § Parallel to cleavage.

Limestone, Av. Range—0.02 to 0.025 (*See also* p. 315)

Dolomite, Mansfield, Nottingham	.029	(17)
Magnesian, South Shields, England	.024	(17)
Oolitic, Musashi, Japan	.022	(40)
Oolite, Caen, Normandy	.020	(17)
Dolomite, Prov. Buzen, Japan	.018	(40)
Gritty, Boniss Island	.015	(40)
Coral, Boniss Island	.009	(40)

Conglomerate

Nagelflue, St. Gallen	0.025	(48)
Calumet & Hecla Mine, Mich	.020	(48)

Granite

Porphyry, Prov. Omi, Japan	.024	(40)
Biotite, Aberdeen, Scotland	.023	(17)
Biotite, Prov. Yamashiro, Japan	.022	(40)

Diorite

Prov. Tanba, Japan	.023	(40)

Gneiss

Prov. Yamashiro, Japan	.021	(40)

Amphibolite

	.020	(40)

Porphyrite

Hornblende, Prov. Omi, Japan	.018	(40)
Augite, Prov. Kai, Japan	.016	(40)
Prov. Higo, Japan	.012	(40)

Tuff

Liparite, Prov. Bitchu, Japan	.017	(40)
Liparite, Prov. Harima, Japan	.014	(40)
Prov. Yamato, Japan	.007	(40)
Breccia, Prov. Yamato, Japan	.007	(40)

Rhyolite

Prov. Etchu, Japan	.015	(40)

Basalt (*See also* p. 315)

Prov. Tanba, Japan	.014	(40)

Andesite

Olivine pyroxene, Prov. Idzu, Japan	.013	(40)
Pyroxene, Prov. Satsuma, Japan	.006	(40)

Travertine

Campagna Romana	.011	(48)

Lava

Mt. Vesuvius	.008	(48)

Shale

	.008	(40)

Marble

Alabama white marble of density 2.7 g cm^{-3}, and sp. ht. 0.213 cal g^{-1}/°C gave (49), 50–100°C, 0.0257: 100–200°C, 0.0206.

Thermal Diffusivity (40)

$cm^2\ sec^{-1}$

Quartzite

Variegated, Prov. Bungo, Japan	0.031
Red, Prov. Bungo, Japan	.023

Schist

Piedmontite, Prov. Awa, Japan	.027
Talc, Prov. Awa, Japan	.014
Epidote, Prov. Awa, Japan	.008

Sandstone

Compact, Prov. Kawachi, Japan	.014
Feldspathic, Prov. Awa, Japan	.012

Granite

Biotite, Prov. Yamashiro, Japan	0.013
Porphyritic, Prov. Omi, Japan	.012
Hornblende, Prov. Mikawa, Japan	.009
Two mica, Prov. Mikawa, Japan	.006

Gneiss

Granite, Prov. Yamashirò, Japan	.013

Serpentine

Peridotite, Prov. Hitachi, Japan	.013

Diorite

Prov. Tanba, Japan	.012

Limestone

Oolitic, Prov. Musashi, Japan	.011
Dolomite, Prov. Buzen, Japan	.008
Gritty, Boniss Island	.007
Coral, Boniss Island	.005

Marble (*See also infra*)

White calcite, Prov. Mino, Japan	.011
White, Alabama (49)	.0106

Tuff

Liparite, Prov. Harima, Japan	.009
Breccia, Prov. Yamato, Japan	.005
Pumiceous, Prov. Ugo, Japan	.004

Gabbro

Hornblende, Prov. Awadi, Japan	.008

Rhyolite

Prov. Etchu, Japan	.008

Basalt

Prov. Tanba, Japan	0.007

Andesite

Olivine, Prov. Idzu, Japan	.006
Pyroxene, Prov. Satsuma, Japan	.005
Shale	.004

LITERATURE

(For a key to the periodicals see end of volume)

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CLAYS

H. Ries

Contents	Matières	Inhaltsverzeichnis	Indice
Density.	Densité.	Dichte.	Densità.
Porosity.	Porosité.	Porosität.	Porosità.
Tensile strength.	Résistance à la traction.	Zugfestigkeit.	Resistenza alla trazione.
Transverse strength.	Résistance à la flexion.	Biegefestigkeit.	Resistenza alla flessione.
Modulus of rupture.	Module de rupture.	Bruchmodulus.	Modulo di rottura.
Drying shrinkage.	Retrait à la dessication.	Trockenschwindung.	Contrazione per essiccamento.
Firing shrinkage.	Retrait à la cuisson.	Brennschwindung.	Contrazione al fuoco.
Water of plasticity.	Eau de plasticité.	Anmachwasser.	Acqua di plasticità.
Fusion points.	Points de fusion.	Schmelzpunkte.	Punti di fusione.
Thermal reactions.	Réactions thermiques.	Thermische Reaktionen.	Reazioni termiche.
Specific heat.	Chaleur spécifique.	Spezifische Wärme.	Calore specifico.
Dehydration behavior.	Conduite à la déhydratation.	Verhalten bei der Entwässerung.	Comportamento alla disidratazione.
Refractive index.	Indice de réfraction.	Brechungsindex.	Indice di rifrazione.
Properties of Bentonite clays.	Propriétés des argiles de Bentonite.	Eigenschaften der Bentonite Tone.	Proprietà delle argille Bentonite.

List of Clays and Their Index Numbers

For properties, *v.* Figs. 1, 2, 3

Index No.	Type of clay	Index No.	Type of clay
1	Allophane	40	Laclede Christy raw flint clay
2	Atlas	41	Maryland flint clay
3	American ball clay	42	Ohio flint clay
4	Dorset ball clay	43	Semi-flint clay
5	English blue ball clay	44	Gibbsite
6	English white ball clay	45	Glass pot clay
7	Tennessee ball clay	46	Glenboig fire clay
8	Ayrshire bauxitic clay	47	Halifax clay
9	Bentonite	48	Halloysite
10	Refractory bond clay	49	Helmstadt clay
11	Brazil, Ind., clay	50	Kaolinite
12	Brick clay	51	Kaolin
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15	Paving brick clay	54	Australian kaolin
16	Plastic clay for No. 1 fire brick, Md.	55	Crude kaolin
17	Plastic clay for No. 2 fire brick, Md.	56	Eger kaolin
18	Bunzlau clay	57	Geisenheim kaolin
19	Cornwall china clay	58	Georgia kaolin
20	English china clay	59	Halle kaolin
21	Crucible clay	60	North Carolina kaolin
22	Czechoslovakia clay	61	St. Yrieix kaolin
23	Diaspore clay	62	Texas kaolin
24	English fire clay	63	Washed kaolin
25	Farnley fire clay	64	White sedimentary kaolin
26	Grossalmerode fire clay	65	Zettlitz kaolin
27	Halle Saxony fire clay	66	Lower Kittanning clay
28	Kittanning No. 2 fire	67	Lower Mercer clay
29	Lischwitz fire	68	Sagger clay
30	Löthian fire	69	Sewer pipe clay
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32	Meissen fire	71	Galesburg, Ill. shale
33	Ohio fire	72	Illinois shale
34	Ohio plastic fire	73	Ohio shale
35	Vallendar fire	74	Stoneware clay
36	Flint clay for No. 1 fire brick, Ky.	75	Cleveland surface clay
37	Flint clay for No. 1 fire brick, Md.	76	Georgia surface clay
		77	Ohio surface clay
38	Flint clay for No. 2 fire brick, Md.	78	Tionesta clay
		79	Velten clay
39	Flint clay for No. 1 fire brick, Md. and Ky.	80	Plastic fire clay
		81	Flint clay

Effect of Firing on Transverse Strength of Clay (10)

Clay	*	Modulus of rupture: Dried at 110°C, lb. in.$^{-2}$	Fired clay, hundred lb./in.^{2}: Cone 6	Cone 8	Cone 10
Tionesta clay: Ellis, Muskingum County, Ohio.	R	390	46	67	38
	W	468	72	83	53
Tionesta clay: Crooksville, Perry County, Ohio.	R	179	20	30	20
	W	315	66	71	37
Lower Kittanning clay (unweathered): Roseville, Muskingum County, Ohio.	R	219	32	34	27
	W	320	86	87	75
Lower Kittanning clay: Toronto, Jefferson Co., Ohio.	R	384	28	23	23
	W	532	79	48	57
New Brighton, Beaver County, Pa.	R	194	29	31	19
	W	191	49	58	34
New Brighton, Beaver County, Pa.	R	195	26	33	15
	W	321	51	52	47
Fire brick, Lawrence County, Ohio.	R	325	41	51	30
	W	499	104	72	62
Nelsonville, Hocking County, Ohio.	R	247	16	35	20
	W	350	47	62	50
Lower Mercer clay: White Cottage, Muskingum County, Ohio.	R	132	30	32	17
	W	251	57	73	47
Mogadore, Summit County, Ohio.	R	143	20	23	22
	W	259	46	48	34
Semi-flint clay: Scioto Furnace, Scioto County, Ohio.	R	94	16	21	20
	W	270	37	74	27

* R indicates run of mine, ground to pass a 20 mesh sieve. W indicates washed clay passing a 150 mesh sieve.

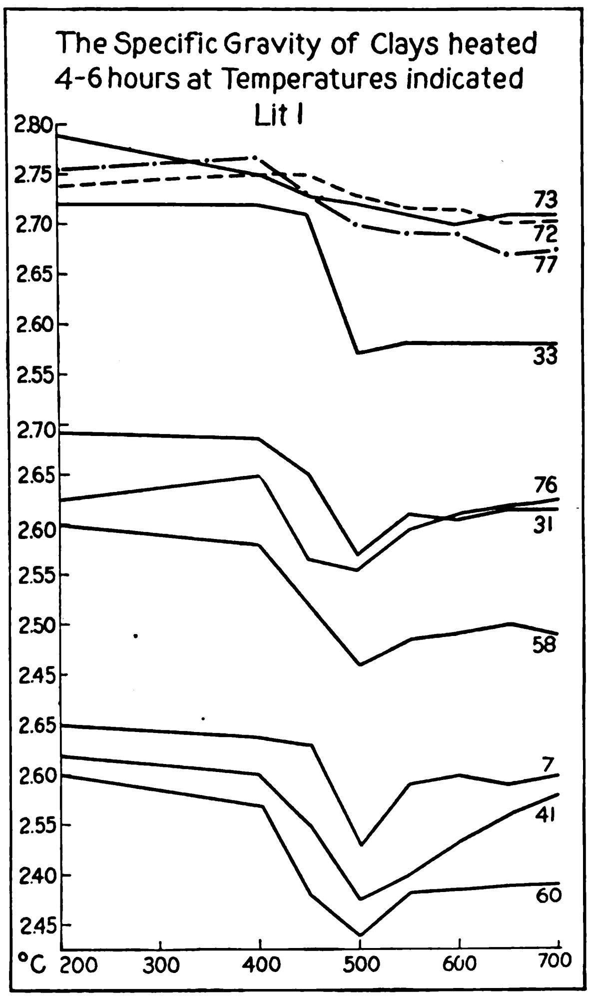


Fig. 4.

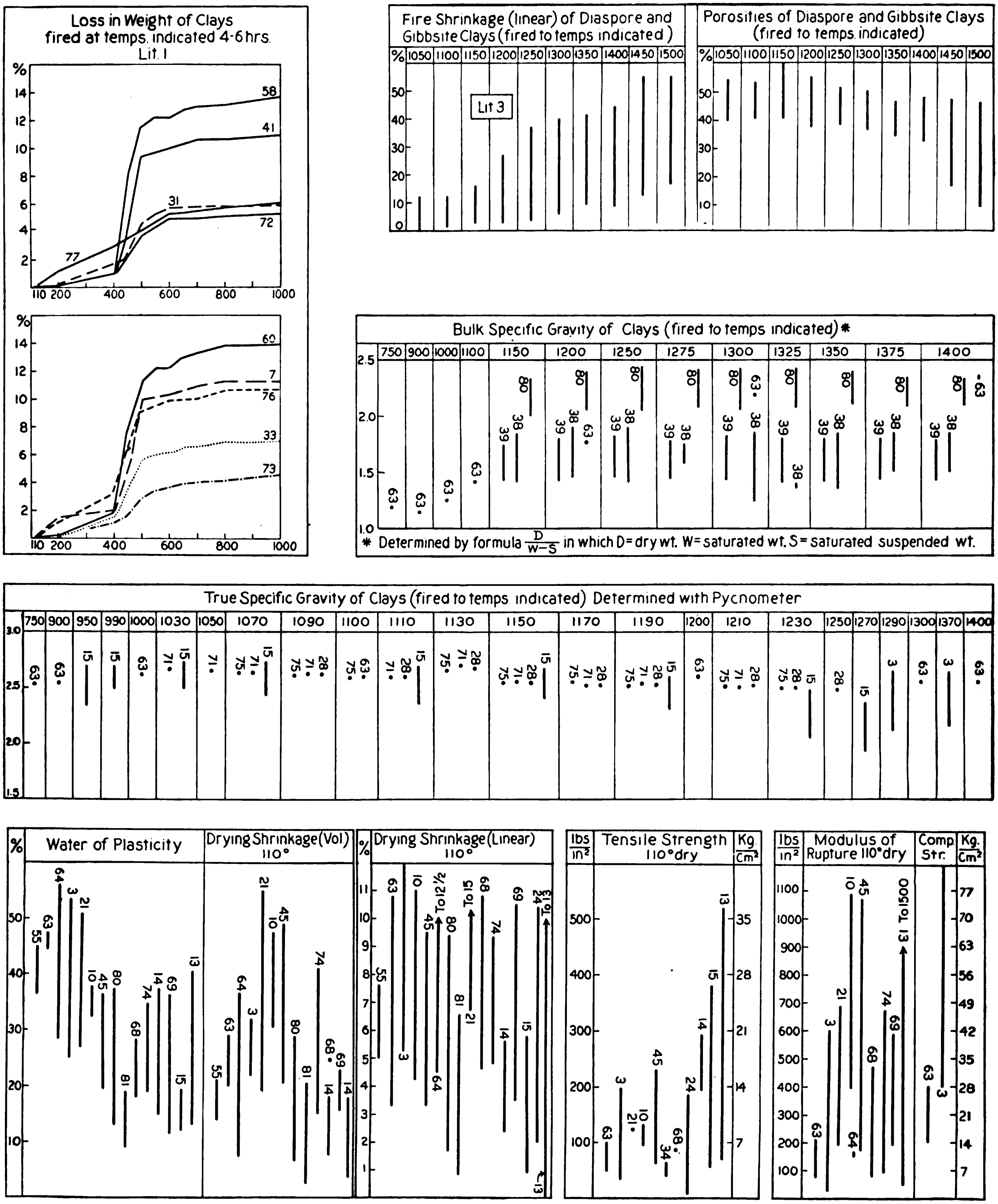

Loss in Weight of Clays fired at temps. indicated 4-6 hrs. Lit. 1
Fire Shrinkage (linear) of Diaspore and Gibbsite Clays (fired to temps indicated)
Lit 3
Porosities of Diaspore and Gibbsite Clays (fired to temps. indicated)
Bulk Specific Gravity of Clays (fired to temps indicated)*
* Determined by formula D/(W−S) in which D = dry wt. W = saturated wt. S = saturated suspended wt.
True Specific Gravity of Clays (fired to temps indicated) Determined with Pycnometer
Water of Plasticity
Drying Shrinkage (Vol) 110°
Drying Shrinkage (Linear) 110°
Tensile Strength 110° dry
Modulus of Rupture 110° dry
Comp. Str.

FIG. 1.

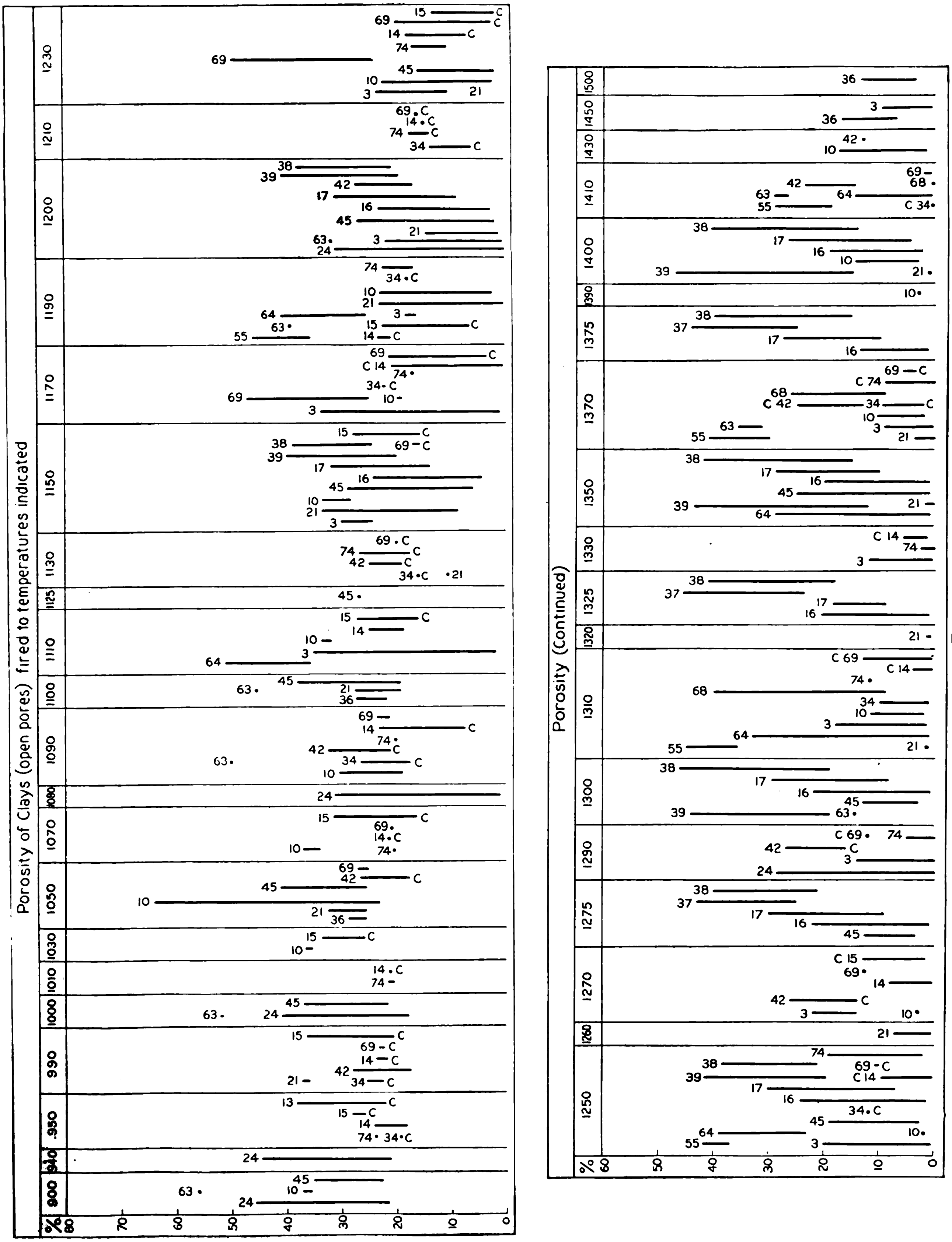

Porosity of Clays (open pores) fired to temperatures indicated
Porosity (Continued)

FIG. 2.

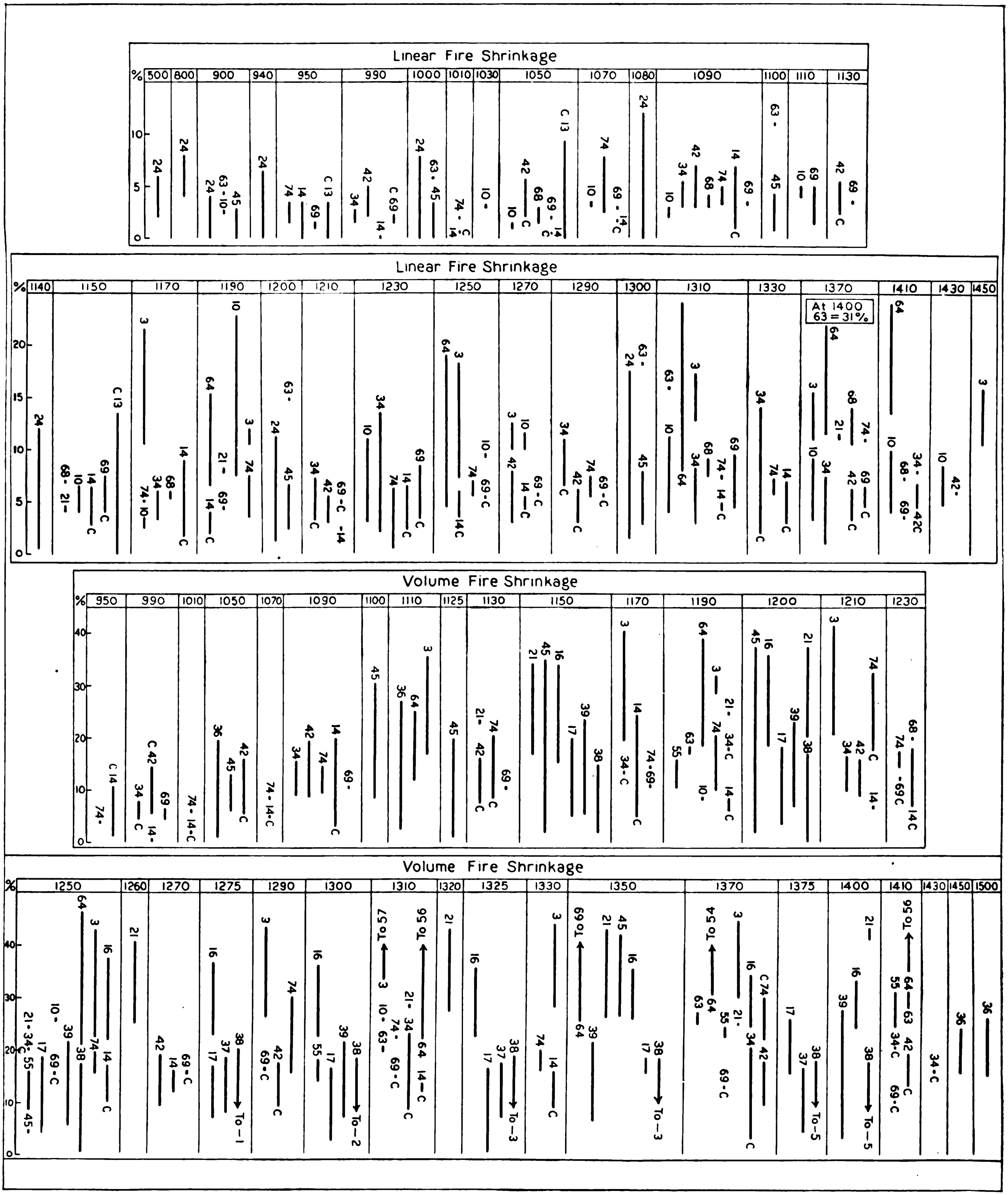

Linear Fire Shrinkage
% 500 800 900 940 950 990 1000 1010 1030 1050 1070 1080 1090 1100 1110 1130
Linear Fire Shrinkage
% 1140 1150 1170 1190 1200 1210 1230 1250 1270 1290 1300 1310 1330 1370 1410 1430 1450
At 1400 63 = 31%
Volume Fire Shrinkage
% 950 990 1010 1050 1070 1090 1100 1110 1125 1130 1150 1170 1190 1200 1210 1230
Volume Fire Shrinkage
% 1250 1260 1270 1275 1290 1300 1310 1320 1325 1330 1350 1370 1375 1400 1410 1430 1450 1500

Fig. 3.

Linear Fire Shrinkage and Porosities of Diaspore and Gibbsite Clays (3)

B. T. = burning temperature. S = shrinkage. Por. = Porosity

B. T., °C	% S	% Por.	B. T., °C	% S	% Por.
1050	0–13	39–54	1300	5–40	36–50
1100	1–13	40–53	1350	9–42	34–48
1150	2–18	40–60	1400	9–44	32–49
1200	2–27	37–55	1450	12–55	16–48
1250	4–38	38–51	1500	17–55	9–46

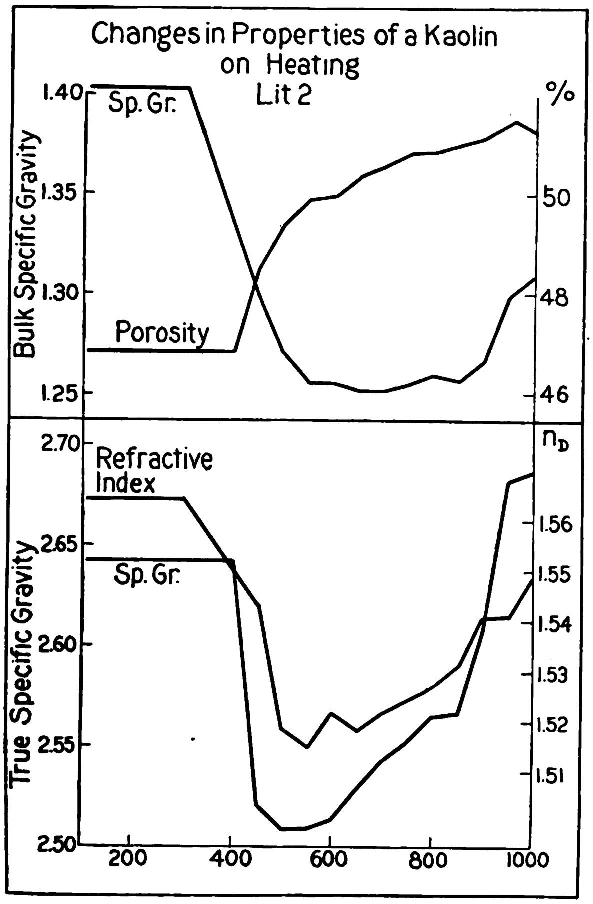


Fig. 5.

Water Ratios to Clay Volume and Weight

Clay	Ratio of pore water to shrinkage water	% water in terms true clay volume	% shrinkage water in terms true clay volume	% pore water in terms true clay volume
Ball clays	0.64–1.10			
Crucible clays	0.56–1.36	69.5–132.5	37.2–84.8	40.5–55.1
Refractory bond clay			15.5	
Glass pot clays	0.65–1.54	53.4–132.5	26.8–77.4	26.6–59.4
Plastic fire clay, Md.				
No. 1 fire brick	1.09–2.08			
No. 2 fire brick	1.13–4.15			
Stoneware clay	0.61–1.16	75–90.6	37.1–55.6	34.0–45.0

Fusion Point in Cones

Clay	Seger cone
Kaolin, washed	33 –35
White sedimentary, Ga. and S. C.	34 –35
Ball clays	30 –35
Crucible clays	30 –
Refractory bond clays	28 –33
Glass pot clays	21½–32
Stoneware clays	18 –32
Plastic fire clays, various localities	27 –35
Md., bond in No. 2 fire brick	31 –32
Flint clays, Md	32 –35
Md., No. 2 fire brick	28 –31
Ohio	31 –32½
Sagger clays	27 –28
Face brick clays	17 –30½
Common brick clays	1 –10

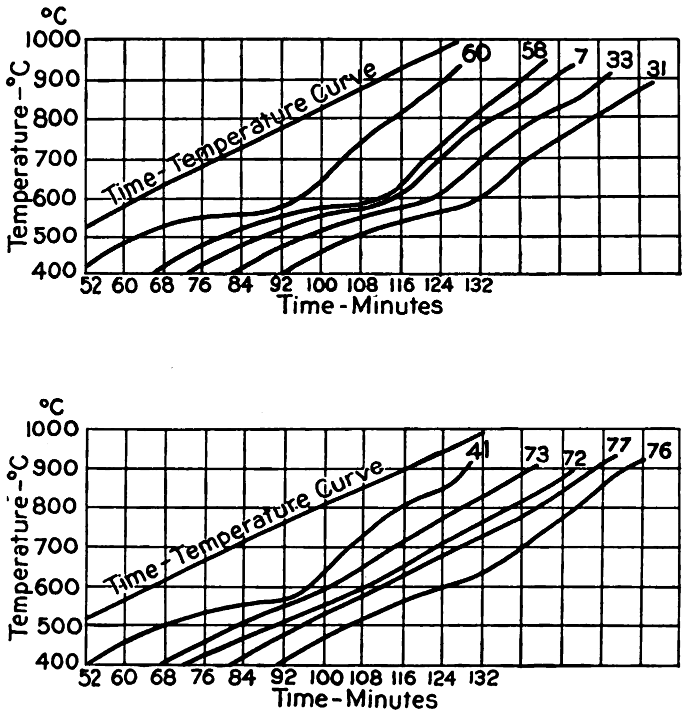


Fig. 6.—Heating curves of clays (1).

Thermal Reactions in Clay with Temperatures at Which Reactions Have Been Noted (2), *cf.* (7)

Clay	Endothermic, °C		Exothermic, °C
Kaolin		500	950
Ayrshire bauxitic clay		530	950
Dorset ball clay	110	500	920
Farnley fire clay	90	510	910
Atlas clay	80	490	930
Aluminous shale	90	510	920
Halifax clay after experimental electro-osmosis	90	520	915

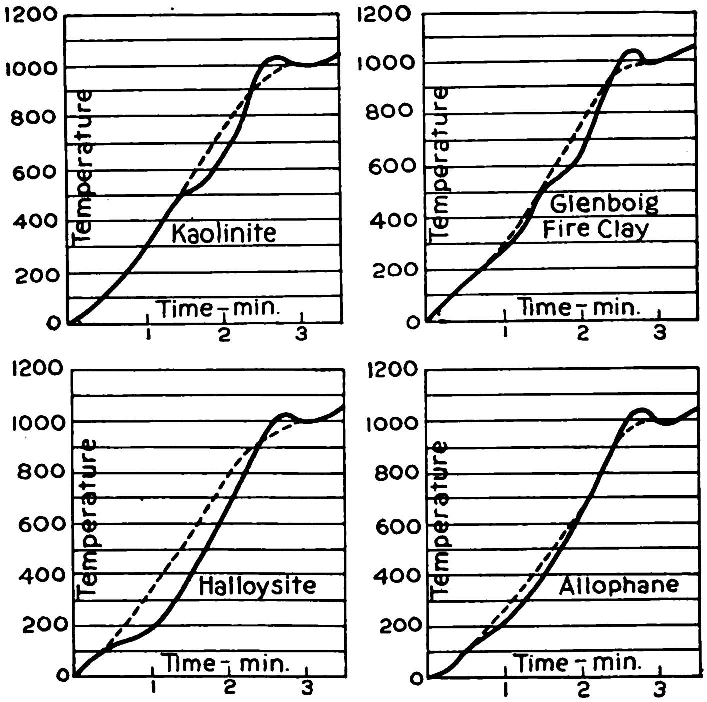


FIG. 7.—Heating curves of air-dried clays (4).

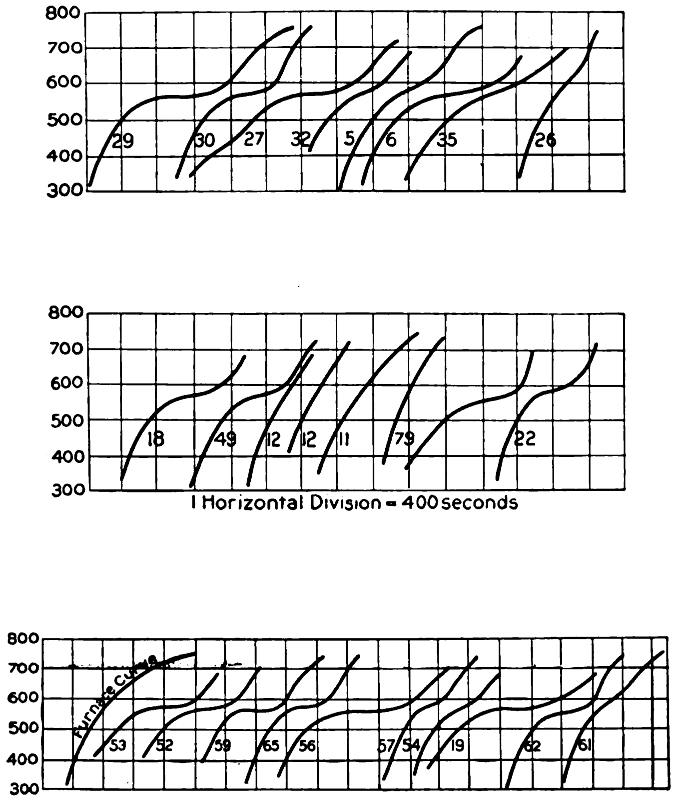


FIG. 8.—Heating curves of various clays (8).

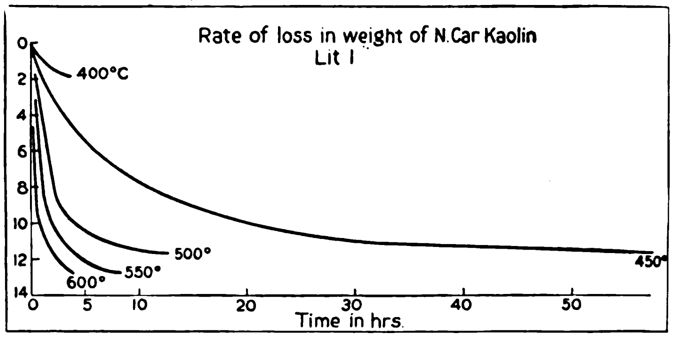


FIG. 9.

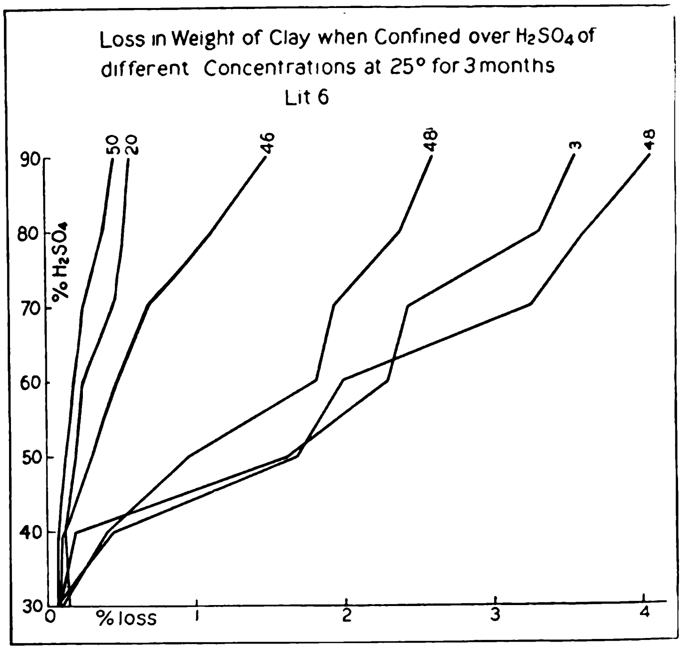


FIG. 10.

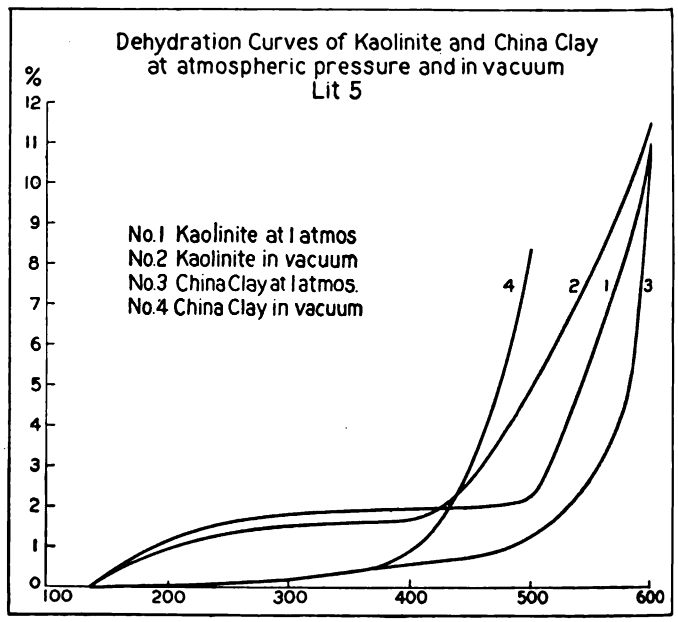


FIG. 11.

Heat Absorbed and Evolved by Clay during Firing and Cooling, g-cal/g (7)

For the first two clays the values given are the average results of two independent experiments and the deviations from this average are indicated

Clay type	Loss on ignition, %	Heat absorbed per g per deg. on heating the air-dried (110°) clay over the temperature ranges given				Heat evolved per deg. on cooling the resulting quantity of fired clay			Specific heat of the fired clay cal/g	Dehydration period		
		25–420°	420–900°	900–1200°	25–1200°	1200–900°	900–700°	1200–700°	1200–700°	Pressure rises, deg.	Period of max. pressure, 20 mm, deg.	Pressure falls to 3 mm, deg.
N. C. kaolin	14.0	0.49 ±0.07	0.69 ±0.05	0.23 ±0.01	0.50 ±0.035	0.23 ±0.01	0.28 ±0.06	0.24 ±0.05	0.28 ±0.05	25–460	460–570	570–780
A-1 English china	12.5	0.42 ±0.01	0.95 ±0.07	0.075 ±0.004	0.55 ±0.07	0.17	0.31	0.20	0.23	25–480	480–540	540–760
Tenn. ball No. 5	13.8	0.47	0.53	0.51	0.51	0.20	0.33	0.25	0.29	25–470	470–550	550–830
Laclede-Christy raw flint	13.0	0.47	0.68	0.24	0.50	0.17	0.37	0.25	0.29	25–470	470–630	630–850
Average		0.46			0.51	0.19	0.32	0.24	0.27			

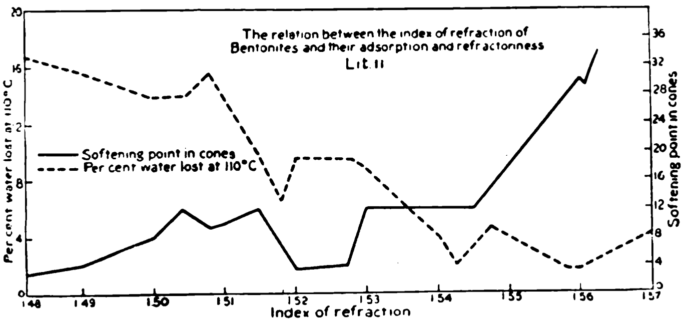


Fig. 12.

Bentonite (12), *cf.* (9)

1. Source of samples tested: 1. Quilchena, British Columbia; 2. Camrose, Alberta; 3. Rosedale, Alberta; 4. Newcastle, Wyo.; 5. Medicine Bow, Wyo.

Sample No	1	2	3	4	5
Sp. gr. (pycnometer)	2.44	2.73	2.72	2.77	2.78
Softening point, cone	15		14	11	10
Refractive index	1.547		1.558	1.557	
Water absorption, g per g	1.53	4.15	4.71	4.93	4.95
Loss on ignition, %					
Air drying	4.64	3.70	4.28	3.67	
At 450°C	4.04*				
At 500°C	3.94	3.60*		3.49	
At 550°C			4.17*		
At 600°C	2.53	2.09		3.43*	
At 700°C	1.50	1.14		0.77	
% remaining on 200 mesh sieve	2.18	1.58	3.16	0.95	1.21
% passing 200 mesh which settles out of water in 24 hr	76.72	10.10	13.14	29.75	11.59
% in suspension in water after 24 hr	21.10	88.32	83.70	69.30	87.20

* Capability of swelling completely destroyed.

Coagulating Effects of Reagents upon Bentonite

Water suspensions

Sample No. / Reagent	1		3		4	
	10 g in 500 cc H_2O		2 g in 500 cc H_2O			
	Reagent, cc	Precipitate, cc	Reagent, cc	Precipitate, cc	Reagent, cc	Precipitate, cc
N HCl	4	200	10	225	4	175
$\frac{1}{2}N$ NaCl	17	200	19	275	18	215
$\frac{1}{2}N$ NH_4Cl	14	225	19	250	19	475
$\frac{1}{2}N$ $BaCl_2$	4	165	9	200	14	185
$\frac{1}{2}N$ $CaCl_2$	7	175	5	200	10	180
$\frac{1}{2}N$ $AlCl_3$	2	200	3	215	4	225
N HNO_3	4	195	3	275	4	225
$\frac{1}{2}N$ KNO_3	11	200	15	225	10	375
$\frac{1}{2}N$ NH_4NO_3	12	200	19	220	19	485
$\frac{1}{2}N$ Ba $(NO_3)_2$	5	200	3	200	4	200
$\frac{1}{2}N$ $Al(NO_3)_3$	3	220	2	215	4	225
N H_2SO_4	3	175	3	175	5	125
$\frac{1}{2}N$ Na_2SO_4	13	200	19	435	18	180
$\frac{1}{2}N$ $(NH_4)_2SO_4$	11	230	19	260	30	275
N $Al_2(SO_4)_3$	5	175	4	200	12	175
Satd. $CaSO_4$	No coagulation up to 50 cc				35	230
Satd. $Ca(OH)_2$	No coagulation up to 50 cc				36	185
$\frac{1}{2}N$ NaOH	No coagulation up to 50 cc		14	285	28	380
NH_4OH (0.9 sp. gr.)	No coagulation up to 100 cc				No coagulation up to 50 cc	
$\frac{1}{2}N$ $(NH_4)_2CO_3$	20	225	40	210	20	215
$\frac{1}{2}N$ Na_2CO_3	No coagulation up to 100 cc		14	300	25	230
CO_2	No coagulation		No coagulation		No coagulation	
$\frac{1}{2}N$ $Na_2C_2O_4$	No coagulation up to 40 cc		No coagulation up to 50 cc		30	300
CaO	g 0.3	150	g 0.5	225	g 0.3	200

Effect of Dilution, Coagulation and Precipitation

Ten g of sample No. 3 agitated in 350 cc of water and diluted to volume given

Volume in liters / Days	% in suspension after, days: 1	4	6	10	120
0.5	88.5	87.3	87.3	60.7	
1.0	86.5	74.1	63.4	56.7	33.6
1.5	85.4	71.3	58.3	48.5	
2.0	83.3	60.1	55.0	42.6	34.4
3.0					29.6
4.0					27.6
5.0					25.1

Properties of Some Clay-Like Minerals of the Bentonite Type(11)

Source	Index of refraction n_D	% water lost at 110°C after air drying	Softening point, cone	% water of plasticity in terms dry wt.	% vol. shrinkage in terms dry vol.	Drying behavior*	Color after firing†
Sanders, Ariz	1.48	16.6	3	71.83	69.08	B	Bf
Daggett, Cal	1.495–1.505	14.87	8	69.52	94.21	B	Bf
Creede, Colo., No. 1	1.505	14.93	12	48.07	59.00	A	Bf
Lovelock, Nev	1.505–1.525	10.82	12	78.10	77.26	C	Bf
Newcastle, Wyo	1.5175	7.26	9	114.61	161.39	B, E	Bf
Wyoming	1.5175–1.5375	9.25	4	99.21	162.73	B, D	Br
Belle Fourche, S. D	1.525–1.535	8.79	12	108.07	195.81	B, E	Bf
Creede, Colo., No. 2	1.545	1.83	12	37.30	30.16	C	Bf
Enid, Miss	1.5475	4.64	14	46.16	73.25	C	Bf
Camden, Ark	1.5575	2.19	27	37.30	41.94	C	W
Grossalmerode clay, Germany	1.56	1.34	27	22.07	24.21	C	W
Las Vegas, Nev	1.56	1.68	30				W
Glass pot clay	1.5615	3.02	29	36.08	41.94	C	W
Houston, Tex	1.563	0.27	34				W
Enid, Miss	1.563	3.25	30	29.75	32.13	C	W
New York	1.57	4.55	1	40.97	47.38	C	Bf

* A = cracks, B = cracks badly, C = does not crack, D = warps, E = becomes very hard on drying. † Bf = buff; Br = brown; W = white.

LITERATURE

(For key to the periodicals see end of volume)

(1) Brown and Montgomery, *32*, No. **21**; 13. (2) Houldsworth and Cobb, *82*, **22**: 111; 23. (3) Howe and Ferguson, *38*, **6**: 496; 23. (4) Mellor, *82*, **16**: 73; 17. (5) Mellor and Holdcroft, *82*, **11**: 169; 12. (6) Mellor, Sinclair and Devereux, *82*, **21**: 104; 22. (7) Navias, *38*, **6**: 1268; 23. (8) Rieke, *100*, **44**: 638; 11. (9) Ross and Shannon, *38*, **9**: 77; 26. (10) Schurecht, *30*, No. **233**; 20. (11) Schurecht and Donda, *38*, **6**: 940; 23. (12) Spence, *Canada*, *Mines Branch*, *Rep.* No. **626**; 24.

HEAVY CLAY PRODUCTS

H. G. Schurecht

1. CLAY BRICK: SPECIFICATIONS AND PROPERTIES

True specific gravity, 2.4–2.6 (7).

Specific heat, 20–100°C, 0.20–0.25 cal g^{-1} $deg.^{-1}C$ (1)

	Bulk density, g/cm³	Water absorption, %	Compressive strength, kg/cm²	Crossbreaking strength, modulus of rupture, kg/cm²
Vitrified brick	2.0–2.2	<5	281 to 351	56 to 84
Hard brick	1.9–2.1	5–12	175 to 281	28 to 56
Medium brick*	1.8–2.0	12–20	105 to 176	21 to 28
Soft brick	1.7–1.9	>20	56 to 105	14 to 21
Paving brick†	1.7–2.2	0.9–8.0	227 to 592	84 to 178

* Thermal conductivity = 1.6 kg-cal m^{-2} hr^{-1} $(°C, m^{-1})^{-1}$ (7), *see also* p. 314).

† Rattler loss, 22–26 % (1).

2. SAND-LIME BRICK

Compressive Strength of Sand-lime Brick Walls (9)

Walls 1.83 m long and 2.74 m high

Wall No.	Thickness, cm	Mortar	Compressive strength, kg/cm²: First crack	Compressive strength, kg/cm²: Failure
1	21.3	Lime	15.3	22.2
2	33.5	Lime	14.1	20.4
3	21.1	Cement-lime	34.0	47.8
4	33.2	Cement-lime	38.7	39.7
5	21.3	Cement	50.4	67.5
6	32.7	Cement	48.1	59.8

SAND-LIME BRICK (2)

Dry brick			Effect of wetting. % change in		Effect of freezing. % change in			Effect of fire. % change in		
Compressive strength, kg/cm²		Cross-breaking strength, modulus of rupture, kg/cm²	Compressive strength	Crossbreaking strength	Compressive strength	Crossbreaking strength	Absorption	Compressive strength		Crossbreaking strength
American method	German method							Dry	Wet	
122–706	66–185	14–83	+17 to −55	+25 to −75	+38 to −55	−22 to −46	+3.8	+53 to −100	−42	−72 to −95

PER CENT WATER ABSORPTION OF SAND-LIME BRICK (10)

Plant		1 hr	24 hr	Total (boiling 5 hr)
A	Maximum	10.6	12.0	17.7
	Minimum	4.2	8.2	10.6
	Average of 1000	6.8	9.7	13.3
B	Maximum	7.9	15.3	18.0
	Minimum	4.8	11.3	12.8
	Average of 54	6.1	13.2	15.6
C	Maximum	6.9	11.9	18.3
	Minimum	5.1	10.8	15.9
	Average of 6	6.0	11.3	16.9
D	Maximum	10.5	14.2	20.6
	Minimum	5.4	11.1	15.6
	Average of 56	7.1	12.2	17.3
E	Maximum	14.4	15.4	22.0
	Minimum	5.8	13.2	18.2
	Average of 50	8.1	14.1	20.0
F	Maximum	16.3	16.7	23.5
	Minimum	8.0	13.6	18.8
	Average of 51	12.2	14.9	20.7
G	Maximum	18.0	18.4	23.8
	Minimum	13.1	15.9	21.9
	Average of 8	16.1	16.9	22.8
H	Maximum	22.4	23.0	31.2
	Minimum	8.2	16.8	18.3
	Average of 100	16.8	19.5	25.2

3. HOLLOW BUILDING TILE (2)

Water absorption, %	Compressive strength, kg/cm²						Softening temperature, °C
	Gross area including voids			Net area excluding voids			
	End	Edge	Side	End	Edge	Side	
7.5 to 26	69–373	22–185	49–97	162–798	84–315	162–414	1100–1390

5. SANITARY BODIES (4)

	Water absorption, %	Crossbreaking strength, modulus of rupture
Fire clay ware	16 to 18	70 to 92 kg/cm²
Vitreous ware	2 to 3	184 to 230 kg/cm²

6. FLOOR AND WALL TILE (6)

Water Absorption.—Vitreous, 0 to 2%. Semi-vitreous, 2 to 10%. Plain unglazed, 10%.

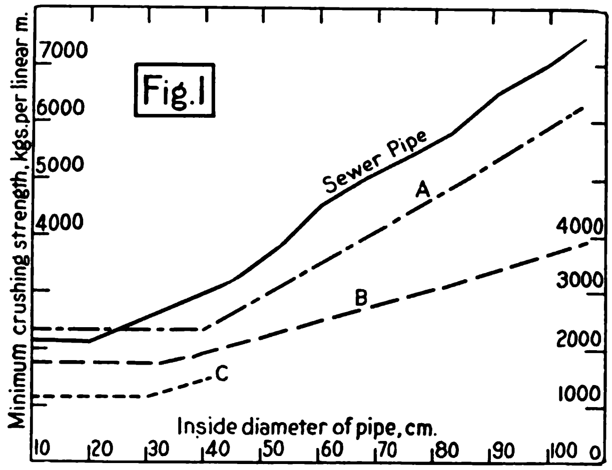
7. DRAIN TILE

A. S. T. M. Specifications (1).

Types.—A, Extra quality, H_2O absorption, 11%; B, Standard, H_2O absorption, 13%; C, Farm, H_2O absorption, 14%. For compressive strength, *see* Fig. 1.

8. SEWER PIPE

A. S. T. M. specifications for vitrified salt-glazed sewer pipe (1). H_2O absorption, 8%. For crushing strength, *see* Fig. 1.



4. STONEWARE (7)

Type	True specific gravity	Bulk density, g/cm³	Water absorption, %	Compressive strength, kg/cm²	Tensile strength, kg/cm²	Crossbreaking strength, modulus of rupture, kg/cm²	Young's modulus of elasticity	Ball compression strength, kg	Resistance to shock, pendulum impact test, cm kg/cm²	Resistance to abrasion, sand blast tests, g/cm²	Hardness, scleroscope	Linear coef. of expansion, per °C	Specific heat, 20–100°C, g-cal g⁻¹ per °C	Softening cone	Heat conductivity, kg-cal m⁻² hr⁻¹ (°C, m⁻¹)⁻¹	Dielectric constant
Common	2.44–2.65	2.06–2.37	0.03–5.1	3248–5833	63–116	234–416	4189–6850	476–1044	1.26–1.90	3.0–9.9	39–62	4.1×10^{-6} to 4.9×10^{-6}	0.185–0.191	17–29	0.95–1.35	
Chemical	2.45–2.53	2.28–2.32	0.13–1.80	5816	163–178	416–980	5087–15130	792–980	1.70–2.40	2.4–3.9	55–64	4.9×10^{-6} to 5.7×10^{-6}		17–30	1.00–1.25	5.17

9. TERRA COTTA BODIES ([5])

Water absorption, 10 to 19 %. Crossbreaking strength, modulus of rupture, 105 to 180 kg/cm^2. Linear coefficient of expansion, 17° to 100°C, (3.7 to 6.0) $\times 10^{-6}$ per °C.

10. CRUSHING STRENGTH OF MASONRY WITH DIFFERENT MORTARS ([8])

Brick employed: 23 × 11 × 5.5 cm (nine different types). *a*, Cement mortar, 1:3. *b*, Lime mortar. *c*, Mortar mixtures. a + b (1:1).

Strength of one meter cubes of masonry in kilograms

a	*b*	*c*
1929	1959	1977
1908	1940	1955
1852	1885	1903
1772	1812	1851
1722	1780	1829
1713	1771	1823
1715	1770	1824
1709	1767	1821
1709	1765	1819

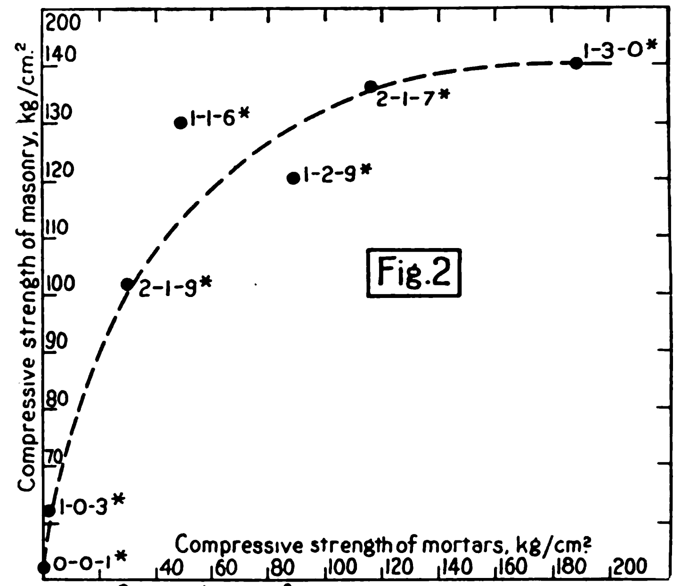
According to Kreuger ([11]) the compressive strength of a brick pier is *ca.* 0.22 × the compressive strength of the brick used in its construction. The corresponding relation to the compressive strength of the mortar used is shown in Fig. 2.

LITERATURE

(For a key to the periodicals see end of volume)

([1]) American Society for Testing Materials, Specifications. ([2]) Emley, *32*, No. **85**: 35; 17. ([3]) Foster, *38*, **7**: 189; 24. ([4]) Fuller, Bureau of Standards, *O.* ([5]) Fuller and Merrit, Bureau of Standards, *O.* ([6]) Pence, *81*, **17**: 484; 15. ([7]) Singer, *Keramik* (Braunschweig, Vieweg und Sohn). 470; 23. ([8]) Svenson, *314*, **36**: 341; 12. ([9]) Whittemore and Stang, *32*, No. **276**: 65; 25.

([10]) Johnson, Bureau of Standards, *O.* ([11]) Kreuger, *314*, **40**: 597; 16.



* Compositions of mortars: lime-cement-sand.

PORCELAIN AND WHITEWARE

I. Electrical porcelain. II. Laboratory porcelain and white ware. Owing to the overlapping of these two classes a certain amount of duplication occurs in the tables but for the complete data both sections should be consulted.

I. Porcelaines électriques. II. Porcelaines et faïences de laboratoire. Etant donné le chevauchement de ces deux classes, il y a un certain nombre de répétitions dans les tables; pour avoir des données complètes, les deux sections doivent être consultées.

I. Elektro-Porzellan. II. Laboratoriums Porzellane und Steingut. Da beide Gattungen in engerrer Beziehung stehen, ist eine gewisse Wiederholung in den Tafeln vorhanden. Doch sollen für vollständige Daten beide Abschnitte herangezogen werden.

I. Porcellane elettriche. II. Porcellane di laboratorio e grès ceramico. Per la stretta relazione tra le due categorie, vi è qualche ripetizione nelle tabelle. Per avere dati completi bisogna però consultare entrambi i capitoli.

I. ELECTRICAL PORCELAIN

Frank H. Riddle[1]

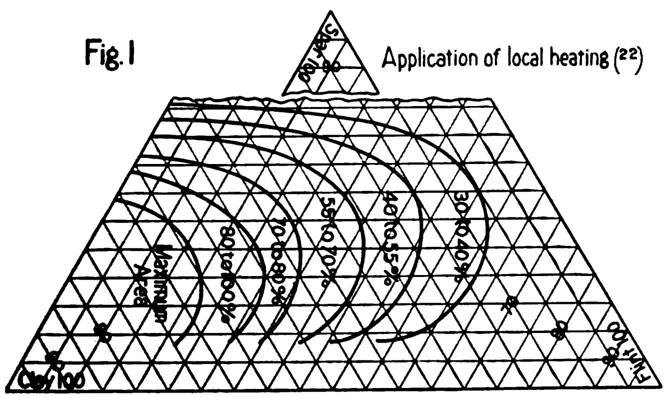
Classification of Porcelains Based on Their Use

I. Normal porcelains.
   (*A*) Low tension porcelain, porosity, 1%.
      Dry or wet process used under 5000 volts. Flint, clay, feldspar porcelain.
   (*B*) High tension porcelain, porosity, 0%.
      Wet process used above 5000 volts. Flint, clay, feldspar porcelains.

II. Special porcelains.
   (*C*) Spark plug core porcelains, porosity, 0%.
      Usually free from free quartz which has objectionable expansion and alkalis which have an injurious effect upon the insulation at increased temperatures.
   (*D*) Heating element porcelains, porosity, 1%.
      Usually containing over 50% magnesia compounds.
   (*E*) Thermocouple porcelains for protection.
      High in alumina and free from free quartz.

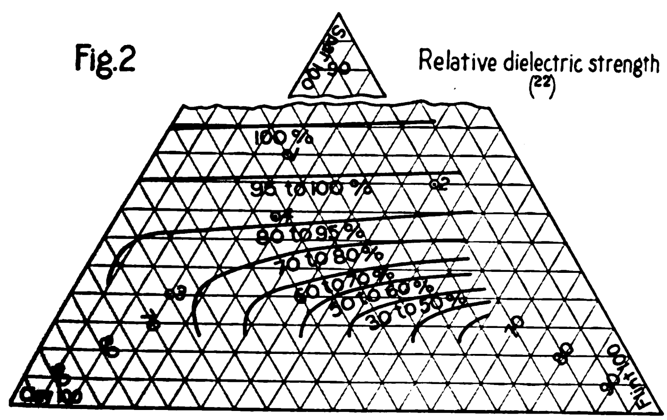
Practically nothing is available in the literature regarding low tension porcelain or heating element porcelain.

Fig. 1



Application of local heating (22)

Fig. 2



Relative dielectric strength (22)

Chemical Composition of Fired Body and Batch Composition of Raw Body

Typical compositions of the possible range of raw bodies are shown in Figs. 1, 2, 3 and 4. These figures can be used only as a general guide, since they do not portray the effects of the different varieties of clay, feldspar and flint, or the methods of grinding, etc.

[1] Grateful acknowledgments are due to Dr. Joseph A. Jeffery for the privilege of carrying out considerable research work in the research laboratories of the Champion Porcelain Company; to Messrs. H. F. Royal, E. K. Bibb, Walter Schmidt, and to Miss Chenoweth and other members of the staff for valuable aid in the assembling and classification of data; and to Messrs. L. E. Barringer and F. W. Peek, Jr., of the General Electric Company, for much valuable information.

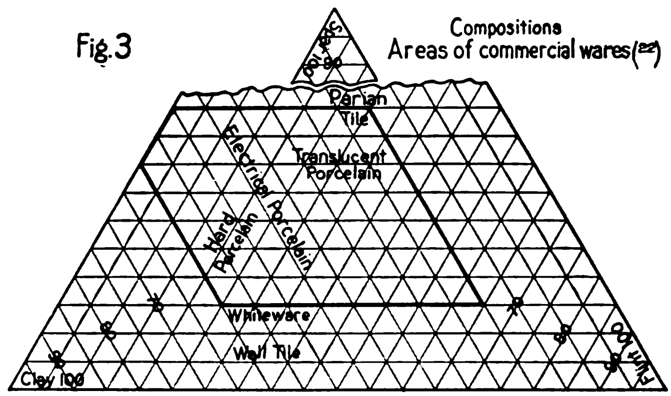
The actual compositions of some of the bodies whose properties are listed in the following pages are shown below, together with the reference numbers by which they are identified in the tables.

Body Compositions

Calcines, wt. % (Chamotte, Aufbereitungsstoffe, Materiali digrassanti)

	Cone	$MgCO_3$	Kaolin	Flint	Al_2O_3	Boric acid
(*A*)	12	14.40	44.30	41.30		
(*B*)	13	18.20	56.00	25.80		
(*C*)	18		70.20		27.80	2.0
(*D*)	18		55.80		44.20	
(*E*)		23.85	76.15			

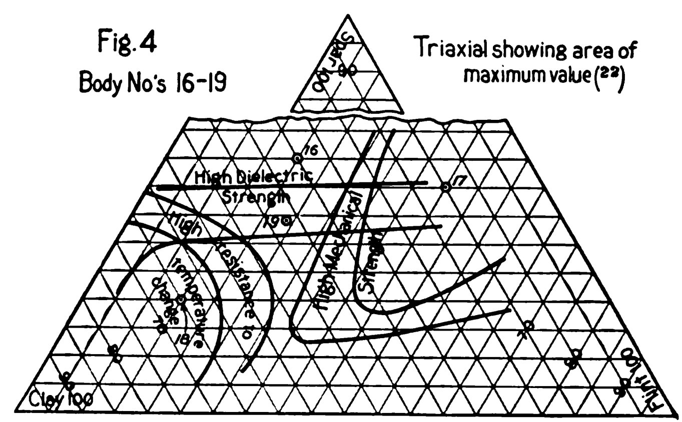
Fig. 3



Compositions Areas of commercial wares (22)

Fig. 4

Body No's 16-19



Triaxial showing area of maximum value (22)

Bodies, wt. % (Matières céramiques, Keramische Massen, Paste ceramiche)

Ref. No.	1	2	3	4	5	6	7	8	9	10	11
Clay	35	35	45	45	50	50	55	55	55	55	65
Flint	40	30	30	20	25	15	10	22.5	15	5	10
Feldspar	25	35	25	35	25	35	35	22.5	30	40	25

Ref. No.	15	16	17	18	19	20	21	22	23	24	25
Clay	40	35	15	65	42	*	22	30.2	40	50.0	50.0
Sillimanite											30.0
Flint	15	20	45	15	24					32.5	2.5
Feldspar	45	45	40	20	34					16.0	16.0
Al_2O_3							18	12.6			
Whiting										1.5	1.5
Calcine							60D	57C	20B 40C		
Cone	10 to 14					18	32	30	17	11	11

* Natural sillimanite (andalusite) with clay bond.

Ref. No.	26	27	28	29	30	31	32	33	34	35
Clay	50.0	50.0	50.0	50.0	45	50	55.0	60	50	45
Calcined clay	20.0	8.5	35.0	5.0						35
Flint	18.5				27	26	15.0	10	30	
Sillimanite		30.0		30.0						
Feldspar	10.0	10.0	13.5	13.5	28	24	28.5	30	8	
Whiting	1.5	1.5	1.5	1.5			1.5			
Calcine									12E	20A

Ref. No.	36	37	38	39	40	41	42	Range %*	Standard %†
Clay	50	50	46	46	50	50	50	40–55	50
Feldspar	25	16	26	21	20	20	20	25–30	30
Flint	25	34	28	33	30	30	30	15–25	20

* For satisfactory bodies (20).
† A standard composition (20).

Chemical Composition

Ref. No.	1	2	3	4	5	6	7	24*	25*	26*	27*	28*	29*
SiO_2	74.08	70.81	69.23	65.96	66.78	63.51	61.08	72.51	52.10	64.59	49.81	55.93	50.38
Al_2O_3	15.63	17.47	18.50	20.34	19.95	21.79	23.22	22.60	42.24	30.86	45.05	38.40	44.10
TiO_2	0.40	0.40	0.56	0.56	0.64	0.64	0.72	0.16	0.12	0.15	0.24	0.19	0.23
Fe_2O_3	0.48	0.50	0.59	0.61	0.64	0.66	0.71	0.14	0.59	0.53	0.64	0.66	0.63
CaO	0.25	0.32	0.27	0.34	0.28	0.35	0.36	1.05	1.10	1.07	1.11	1.13	1.13
MgO	0.22	0.25	0.26	0.29	0.28	0.31	0.33	0.18	0.26	0.22	0.28	0.28	0.27
K_2O	2.72	3.67	2.79	3.74	2.83	3.78	3.82	1.98	2.18	1.58	1.67	2.07	1.98
Na_2O	1.39	1.75	1.57	1.93	1.66	2.02	2.11	1.08	1.31	1.05	1.20	1.34	1.28
Ignition loss	4.83	4.83	6.24	6.24	6.94	6.94	7.65						

* Fired body.

Petrographic Character of Insulator Porcelains

A comparative petrographic study of a number of insulator porcelains of American, French and German manufacture leads to the following conclusion.

A good porcelain insulator made from clay, feldspar and flint should consist largely of a glassy matrix with embedded crystals of quartz and mullite ($3Al_2O_3.2SiO_2$) evenly distributed throughout. The quartz should not exceed 20 to 25%, preferably less, and the fragments should have rounded edges and corners, as indicating partial solution by the feldspar glassy matrix. The average grain size of the quartz should not exceed 0.03 to 0.04 mm diameter, and the particles should be evenly distributed. No clay or partially decomposed clay particles should be present. The crystals of mullite should be abundant, well-formed, evenly distributed, and should not exceed *ca.* 0.01 mm length by 0.002 mm thickness.

Owing to the very close resemblance between mullite and sillimanite crystals, the following crystallographic characterization is given (9, 70).

	Mullite $3Al_2O_3.2SiO_2$	Sillimanite $Al_2O_3.SiO_2$
Crystal system	Orthorhombic	Orthorhombic
Prism angle, $110 \wedge 1\bar{1}0$	89° 13′	88° 15′
Cleavage	∥ 010	∥ 010
Optic orientation	$\dot{c} = \gamma$ and $a = \alpha$	$\dot{c} = \gamma$ and $a = \alpha$
Refractive indices γ	1.654	1.677
Refractive indices α	1.642	1.657
Axial angle, $2V$	+45°, −50°	+25°, −30°

Bulk Density, Specific Gravity and Porosity

1. Typical electrical porcelains for high-tension work

Specific gravity	Bulk density, g/cm³	Open-pore porosity, %	Total porosity, %	Type	Lit.
2.3–2.5				Hermsdorf	(53)
2.46	2.317		5.8	Berlin hard	
2.45	2.233	1.80	8.9	DTS sill. Z54	(53)
2.45	2.276	0.19	7.3	DTS sill. Z55	(53)
	2.24–2.35			In general	(4)
		0.01		Elec. average of 8	(63)
2.46	2.25		7.7	Elec. Ref. No. 15	(48)

2. Special spark plug and vitrified pyrometer porcelains (48)

2.77	2.54	0.00	8.4	"Sill." spark plug 6012, Ref. No. 20
3.03	2.83	0.00	6.8	Artificial mullite, Ref. No. 21
2.89	2.72	0.00	5.7	Artificial mullite, Ref. No. 22

Coefficient of Cubical Compressibility

$\frac{10^6 dV}{V dP} = 1.4$ to 1.8 per atm. The lower figure is for highly siliceous, and the latter for highly feldspathic, porcelains (56).

Tensile Strength (Def. 4)

kg/cm²	Type	Cross section*	Lit.
843.6	Sill. (mullite)	0.864 cm²	(38)
684	Sill. (mullite)	0.864 cm²	(39)
519	Insulator	3.226 cm²	(20)
514	Sill. (mullite)	6.45 cm²	(39)
421.8	Insulator average of 7†	0.864 cm²	(12)
360	Hermsdorf 103	3.14 cm²	(53)
320	Berlin hard	3.14 cm²	(53)
261	Rosenthal H	7½ × 2 cm	(56)
240	Various	7½ × 2 cm	(15)
178	DTS sill. Z54	0.314 cm²	(53)
163	DTS sill. Z55	7½ × 2 cm	(53)
140–260	Various	7½ × 2 cm	
130–200	Hermsdorf		(42)
122	Marquardt	7½ × 2 cm	(53)
98	Insulator	7½ × 2 cm	(45)

* The area of the cross section of the test piece is important, *see* Fig. 5.
† Batch weights and chemical compositions of these bodies are shown under Ref. Nos. 1–7.

Illustrating the Influence of the Glaze

All pieces made of the same body and all burned together (40); *see also* especially (21.1)

kg/cm²	623	720	642	305
Type	No glaze	Best glaze	Good glaze	Crazed glaze

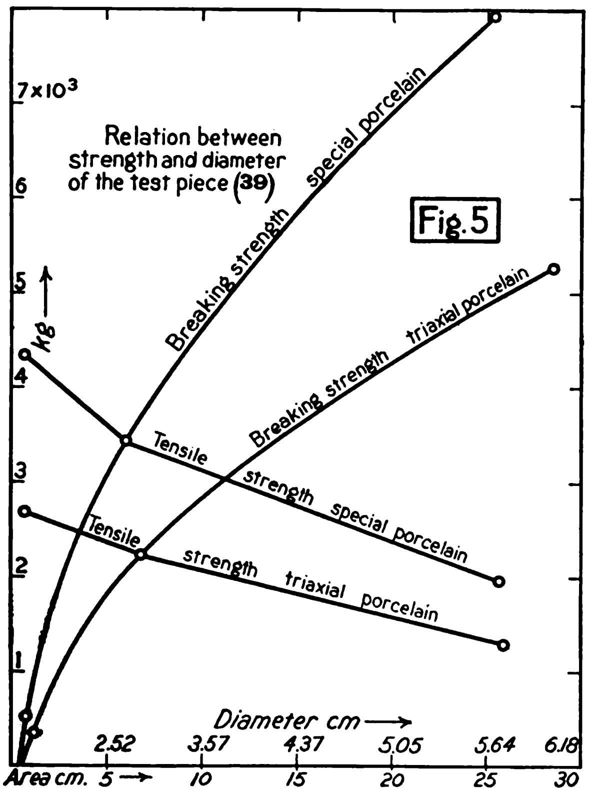
Compare the tensile and crushing strengths of American and German bodies. The German bodies have a greater crushing strength, the American bodies a greater tensile strength.

Modulus of Rupture*

kg/cm²	Type	Lit.	kg/cm²	Type	Lit.
590	Insulator......	(45)	500		(49)
580	DTS sill. Z55..	(53)	490	Hermsdorf.....	(46)
595–469	Average of 7 elec.†........	(38)	416	DTS sill. Z54..	(53)
560–420		(19)	246	Marquardt....	(53)
540	Insulator H...	(46)			

* Extruded cyl. pieces 120 mm long, and 16 mm diam., burned hanging in vertical position and sawed to length. Supported on steel knife edges 10 cm apart and loaded centrally, 1 kg per sec.

† For compositions *see* Ref. Nos. 1–7, inclusive. For effect of glaze *see* (21.1).



Crushing Strength

Unit is 1000 kg/cm²

Strength	Type	Remarks	Lit.
5.8*	DTS sill....................		(53)
>5.6*	Hermsdorf....................		(53)
>5.0*	Rosenthal H.................	2.11 cm²	(46)
4.8–4.2	Hermsdorf....................	16 × 16 mm	(56)
4.5	Insulator....................		(45)
4.2	Berlin hard..................	2.5 cm cubes	(42)
4.0	Sill. average of 7............	4.90 cm²	(39)
4.0†	Insulator....................		(56)
2.5†	Insulator average of 3.........	2.54 cm diam.	(38)
1.6–1.8‡	....	6 × 3 cm	(8)
1.0	Marquardt..................		(53)
4.2–3.1§	Elec. various.................	Cyl. 3.14 cm²	(44)

* The higher values are probably due to the use of cylindrical test pieces instead of square ones. In 1920 the German committee appointed to arrange standard tests decided on a test piece 16 × 16 mm diameter. According to Demuth (15) test pieces smaller than 50 × 50 mm are too small and the high results obtained are misleading.

† For compositions *see* Ref. Nos. 4, 5 and 7.

‡ The higher value is for glazed, the lower for unglazed.

§ For compositions *see* Ref. Nos. 8–11.

Crushing Strength between Spheres* (53)

kg	982	792	748
Type..........	DTS sill. Z55	DTS sill. Z54	Marquardt

* The Gary press (43) used for this test holds a piece 1 cm thick and 10 cm wide between steel balls 31.7 mm in diameter, through which the pressure is applied. Results calculated to correspond to a disc 1 mm thick.

Modulus of Elasticity (Def. 10)

The unit is 1000 kg/mm²

Modulus	Type	Remarks	Lit.
10.6	"G. E."..................	Bending	(10)
10.2	"G. E."..................	Tensile (*v.* Fig. 1)	(10)
8.9	Marquardt................	Bending	(53)
8.7	O. S. Univ................	Tensile	(10)
8.4*	Rosenthal................	Bending	(56)
8.3	Berlin hard...............	Bending average of 72	(59)
8.0–7.0	Hermsdorf................		(53)
7.8	Rosenthal................		(53)
7.8	Insulator.................		(53)
7.1–5.4	Hermsdorf 104............	End support	(19)
7.0	Average..................		(4)
7.0–5.0	Hermsdorf 1915...........		(42)
6.5	DTS sill. Z55.............		(53)
5.1	DTS sill. Z54.............		(53)
8.9	Westinghouse.............	Bending 12.7 mm rod	(20)
6.3	Hermsdorf 1921...........	End support	(56)
5.2	Westinghouse.............	Bending 19 mm rod	(20)

* With varying loads this value varied from 8.4 to 17.9 with the same test pieces and under uniform conditions. Tests made by Steger's method (59).

The modulus is dependent more upon the conditions of manufacture than upon chemical composition. It is substantially the same for tension and compression. For G. E. porcelain Boyd (10) found the following relations: $D = 0.133L$ for compression; $D = 0.133L$ for bending; $D = 0.143L$ for tension; where D = deformation in 0.00001ths. and L = load in kg-cm⁻².

Modulus of Elasticity in Shear (Def. 11)

kg/cm²	Type	Lit.	kg/cm²	Type	Lit.
600–480	Hermsdorf 103	(53)	481	Insulator 101 G	(46)
500	Rosenthal H	(46)	430	Seger 6833*	(46)
500	Rosenthal laboratory porcelain	(46)	323	DTS sill. Z54	(53)

* Square test piece.

Fixed Impact and Bending Shock (Def. 16)*

cm-kg-wt./cm²	Rosenthal porcelains	Lit.	cm-kg-wt./cm²	Type			Lit.
2.4	Spec. 6412..........	(56)	1.9	Hermsdorf			(53)
1.61	Spec. 6048..........	(45)	1.8	DTS sill. Z54			(53)
1.38	Spec. 6048..........	(56)	1.7	DTS sill. Z55			(53)
1.23	Laboratory..........	(56)	Cone 15	Spar	Kaolin	Quartz	Lit.
1.00	Seger 6833..........	(56)					
0.95	Insulator H..........	(56)	1.43	34	48	18	(61)
0.90	Insulator G..........	(56)	1.29	26	46	28	(61)
0.08	Hard 6292..........	(56)	1.23	25	50	25	(61)

* Pendulum-hammer method. 16 × 16 × 120 mm bar, 100 mm span, 10 cm-kg-wt. blow (53).

Successive Increasing Impact Shocks*

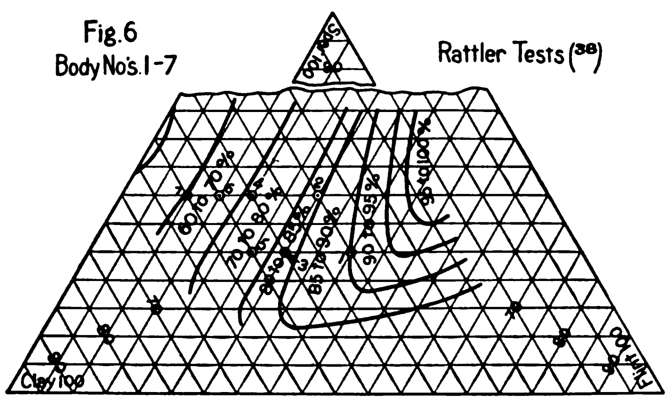
$\frac{\text{cm-kg-wt.}}{\text{cm}^3}$	Rosenthal porcelain	Lit.
146	Stoneware 6412	(56)
117	Laboratory	(56)
105	Insulator H	(56)
98	Insulator G	(56)
69	Seger 6833	(56)
10	Marquardt	(53)

* Marten's method consists in letting a weight drop from successively increasing heights upon a disc-shaped test piece until rupture occurs. The effect is measured in cm-kg-wt. per unit volume of the test piece. Result independent of size of test piece.

Resistance to Abrasion

Gary sand blast test, 2 min at 3 atm

Type	Loss in cm³	Lit.
Insulator G	2.4	(46)
Rosenthal (Selb.) H	3.3	(46)
Marquardt 1	10.3	(14)
DTS sill. Z54	2.5	(53)
DTS sill. Z55	3.9	(53)
Seger hard 6412	1.7	(46)



Toughness and Hardness by the "Rattler" Test*

Per cent loss of weight by rattler test (38)

15 min	30 min	3 hr	Type
2.2	3.5	10.6	1, Fig. 6
3.2	5.2	14.4	2, Fig. 6
4.4	8.8	21.6	3, Fig. 6
8.0	14.5	27.4	4, Fig. 6
5.1	9.6	23.6	5, Fig. 6
7.8	12.2	29.6	6, Fig. 6
10.2	14.2	33.6	7, Fig. 6

* The 15 min test is an indication of the toughness or resistance to chipping. The 3 hr test is an indication of hardness after edges and corners are gone.
Ratio: Marquardt to DTS sill. Z54, is 2.6, time not stated (53).

With a constant clay content the higher spar and lower flint body is invariably weaker. Increase in clay and decrease in flint decreases strength. The compositions of the bodies are plotted on the triaxial diagram, Fig. 6. Note the relation between loss in wt. and body composition.

Tests were carried out under the following conditions: 13 test pieces 2.25 × 2.25 × 5.0 cm with square edges. Tested in porcelain jar mills 24.75 cm diam. × 33 cm long inside rotating at 40 r.p.m. Besides the test pieces there were 61 pebbles weighing 10 kg. The test pieces were removed and weighed at the time specified.

Softening Point

Cone	Type	Lit.
20	Raw: Ref. No. 15	(48)
18	Raw: Ref. No. 16	(48)
15 down	Raw: Ref. No. 17	(48)
31	Raw: Ref. No. 18	(48)
20 down	Raw: Ref. No. 19	(48)
26	American typical insulator	(48)
27	French typical insulator	(48)
31 tipped	German typical insulator	(48)
32 down	"Sill." spark plug	(48)

Softening point varies with size and shape of test piece, time of heating, etc.

Coefficient of Thermal Expansion

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range, °C	Lit.
4.25	Hermsdorf		(53)
4.00	G. E.		(2)
5.42	Lock insulator ('09)	20–101	(65)
5.35	Lock insulator ('09)	19–243	(65)
3.79	High tension	16	(55)
3.79	Rosenthal	20–100	(56)
3.80	Seger 6833	20–100	(53)
6.66	Elec. 1 EL	20–500	(11)
4.36	Elec. 1 EL	20–400	
4.85	Elec. 2 EL	400–600	(11)
5.2	Marquardt		(53)
2.7	Fired to Cone 26 ($Al_2O_3.SiO_2$)	25–200	(37)
3.9	Fired to Cone 26 ($Al_2O_3.SiO_2$)	200–400	(37)
3.3	Fired to Cone 26 ($Al_2O_3.SiO_2$)	25–400	(37)
3.36	"Sill." spark plug; Ref. No. 23	30–200	(6)
4.19	"Sill." spark plug; Ref. No. 23	200–400	(6)
4.78	"Sill." spark plug; Ref. No. 23	400–500	(6)
3.81	"Sill." spark plug; Ref. No. 23	30–400	(6)
5.3	Ref. No. 24	25–400	(37)
3.5	Ref. No. 25	25–400	(37)
5.5	Ref. No. 26	25–400	(37)
3.5	Ref. No. 27	25–400	(37)
3.3	Ref. No. 28	25–400	(37)
3.7	Ref. No. 29	25–400	(37)
6.17	High tension	?	(20)
5.27	High tension	?	(20)
3.43	$Al_2O_3.SiO_2$ vitrified at cone 32	119.0	(67)
3.78	$Al_2O_3.SiO_2$ vitrified at cone 32	230.5	(67)
4.01	$Al_2O_3.SiO_2$ vitrified at cone 32	317.7	(67)
4.16	$Al_2O_3.SiO_2$ vitrified at cone 32	392.7	(67)
4.40	$Al_2O_3.SiO_2$ vitrified at cone 32	512.7	(67)
3.63	$3Al_2O_3.2SiO_2$ vitrified at cone 32	117.0	(67)
3.95	$3Al_2O_3.2SiO_2$ vitrified at cone 32	216.5	(67)
4.18	$3Al_2O_3.2SiO_2$ vitrified at cone 32	304.3	(67)
4.36	$3Al_2O_3.2SiO_2$ vitrified at cone 32	383.3	(67)
4.62	$3Al_2O_3.2SiO_2$ vitrified at cone 32	492.5	(67)
2.37	Average of five refractory porcelains	114.2	(68)
3.07	Average of five refractory porcelains	234.7	(68)
3.69	Average of five refractory porcelains	357.2	(68)
4.00	Average of five refractory porcelains	482.6	(68)
4.21	Average of five refractory porcelains	601.7	(68)
4.51	Average of five refractory porcelains	724.1	(68)
4.84	Average of five refractory porcelains	844.2	(68)

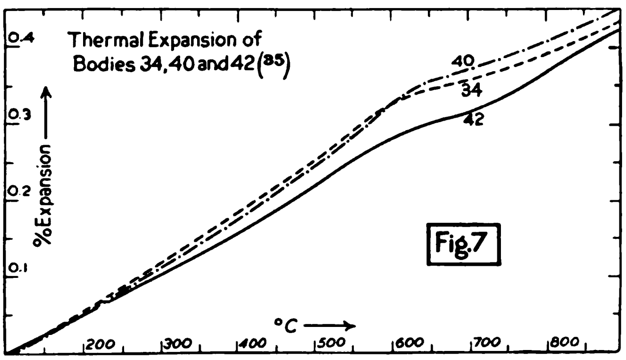
Resistance to Thermal Shock

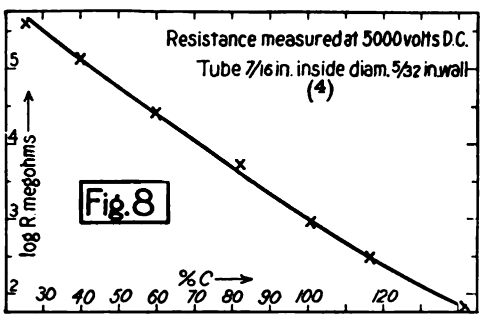
The recorded data are not comparable owing to lack of standard methods *v.* (8, 54, 66, 29). The *relative* heat shock strengths of a series of electrical porcelains covering the whole range of com-

positions is shown in Fig. 4 (22). Substitution of ZrO_2 for SiO_2 improves the resistance to thermal shock (60, 69). "Sillimanite" (mullite) porcelains have a greater resistance than ordinary kinds.

Volume Resistivity

Temp., °C	Sp. resist. Megohm-cm	Type	Lit.
613–900	0.068–1.098		(33)
727	0.007	Berlin	(17)
727–1292	0.100–0.0034		(33)
20	129×10^6		(16)
189	0.385×10^6		(16)
300	19	Stand. G. E. plastic	(2)
350	9		(2)
400	3.5		(2)
500	1.5		(2)
600	0.8		(2)



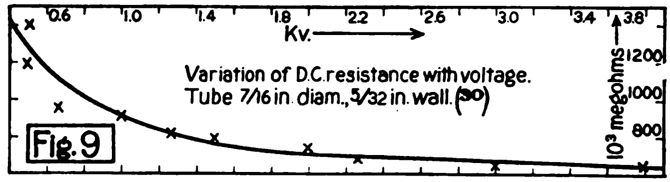


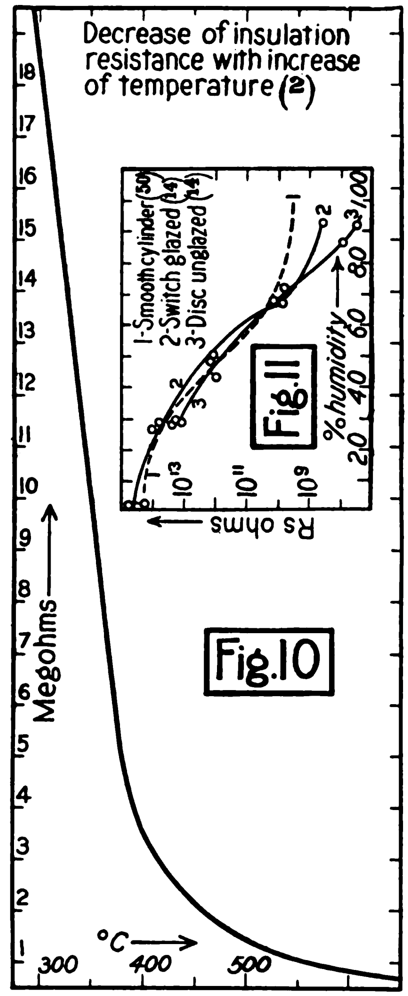
Some experimenters compare porcelains by finding the temperature at which the resistance is equal to one megohm-cm. They have termed this temperature the "effective temperature," T_E; *see also* Figs. 8, 9 and 10.

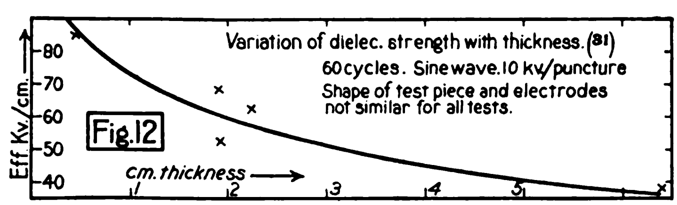
T_E, °C	Composition	Cone	Lit.
370	Ref. No. 30..................	14	(52)
358	Ref. No. 31..................	14	(52)
390	Ref. No. 32..................	12	(52)
400	Ref. No. 33..................	10	(6)
590	Ref. No. 34..................	15	(6)
610	Ref. No. 35..................	16	(6)
690	Ref. No. 23..................	16	(6)

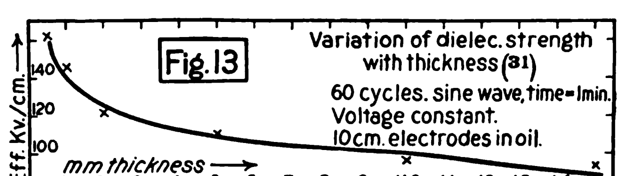
Surface Resistivity

Varies enormously with humidity of the atmosphere and with the nature of the surface film. For variation of the resistivity of a *clean* surface with atmospheric humidity, *see* Fig. 11.









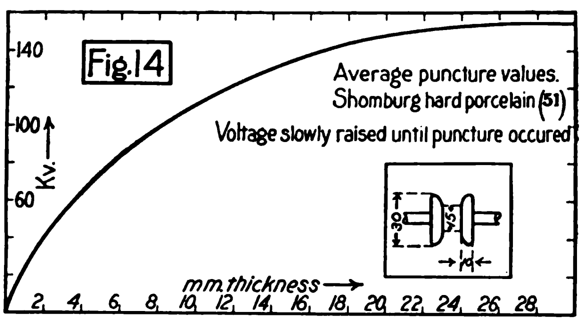
Dielectric Constant

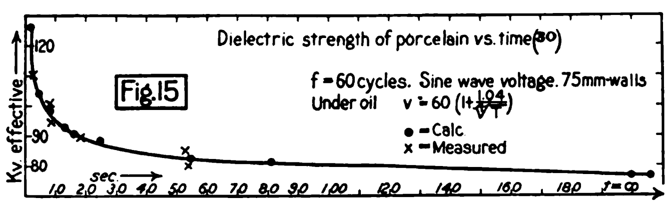
6.15 for a G. E. wet process porcelain at 10^6 cycles, 25°C and 60% relative humidity (2); *see further* p. 80.

Dielectric Strength

1. Shape of the electrodes not given. Voltage increased 1 kv/2 sec, starting at 20 kv under oil

Volts per mm	Type	Remarks	Lit.
10 000	Hermsdorf.........	5 mm thick test porcelain	(19)
9 000	Hermsdorf.........	10 mm thick test porcelain	(19)
$\frac{1}{30}$ of above	....	At 275°C	(19)
16 000	Royal Berlin.......	$2\frac{1}{2}$ mm thick	(42)
17 200	Ref. No. 36......		(61)
12 500	Ref. No. 37......		(61)
18 100	Ref. No. 38......		(61)
20 300	Ref. No. 39......	5 mm discs. Cone 15	(61)
27 400	Ref. No. 40......		(61)
18 300	Ref. No. 41......		(61)
28 700	Ref. No. 42......		(61)





2. 25°C under oil, 12.7 mm electrodes with rounded edges, voltage increased 1 kv per sec

9 100	Ref. No. 16......	Test piece 6.35 mm to 9.14 mm. 60 cycle sine-wave voltage	(3)
9 400	Ref. No. 17......		(3)
10 600	Ref. No. 18......		(3)
8 400	Ref. No. 19......		(3)

According to Peek (31) the puncture tests on solid insulators vary greatly between different samples of the same material, shape and area of the electrodes, time of application of voltage, etc.; *see* Figs. 12–16.

Dielectric Losses

For variation of dielectric losses and power factor with frequency, *see* (25).

Flash-over Voltage

Effect of humidity, Fig. 18.
Effect of length of test piece, Fig. 17.

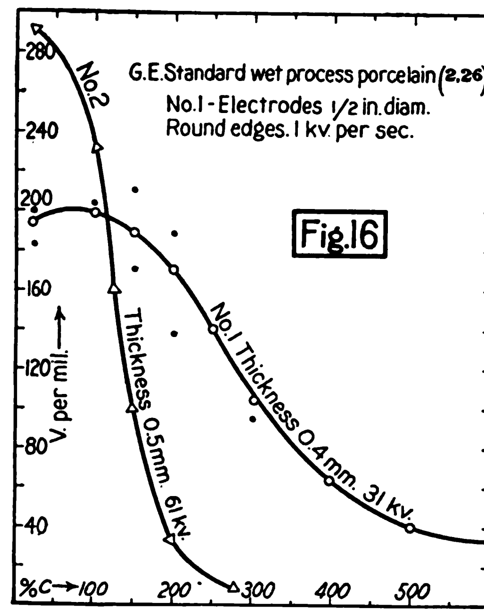
Electrolysis of Hot Porcelain

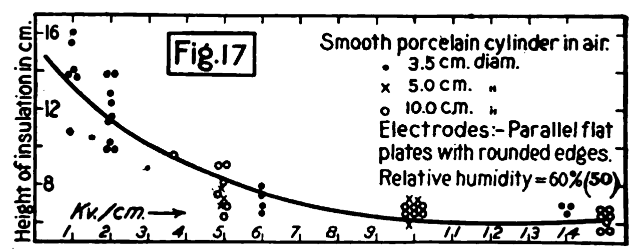
Above 300° porcelain behaves as an electrolytic conductor, the alkali metals migrating toward the cathode. For experimental details, results and conclusions, *v.* Haber (23).

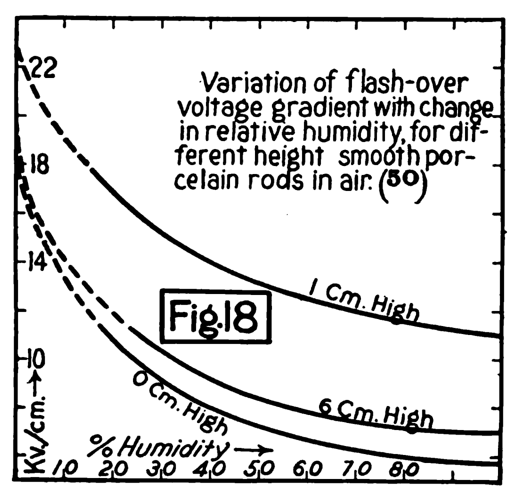
Velocity of Sound

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.63	Insulator H	(46)	5.05	Hermsdorf hard	(46)
5.34	Seger 6833	(46)	4.9–5.2	In general	(56)

Velocity of transmission, or vibration of sound, varies with the modulus of elasticity. Porcelains having the highest velocity are the best. Velocity increases with increasing clay content.







LITERATURE

(For a key to the periodicals see end of volume)

(1) Austin, *129*, **30**: 2303; 11. (2) Barringer, General Electric Co., Schenectady, *0*. (3) Bibb, Jeffery DeWitt Insulator Co., Kenover, West Virginia, *0*. (4) Bleininger, *33*, **16**: 589; 17. (5) Bleininger, *109*, **1919**: 101. (6) Bleininger and Riddle, *38*, **2**: 564; 19. (7) Boudouard, *106*, **1920**: 681. (8) Boudouard, *102*, **24**: 79; 21. *103*, **29**: 496; 21. (9) Bowen, Grieg and Zies, *128*, **14**: 183; 24.

(10) Boyd, *122*, **38**: 222; 16. (11) U. S. Bureau of Standards, *0*. (12) Champion Porcelain Co., Detroit, *0*. (13) Curie, *6*, **17**: 385; 89. (14) Curtis, *31*, No. 234; 14. (15) Demuth, *101*, **41**: 892; 20. (16) Dietrich, *63*, **11**: 187; 10. (17) Doelter, *B10*. (18) Foussereau, *6*, **5**: 241; 85. (19) Friese, *B12*.

(20) E. H. Fritz, Westinghouse Electric and Manufacturing Co., East Pittsburgh, *0*. (21) Gary, *100*, **56**: 429; 23. (21.1) Gerold, *103*, **33**: 188; 25. (22) Gilchrist and Klinefelter, *B6*. (23) Haber, *93*, **57**: 154; 08. (24) Harker, *3*, **10**: 430; 05. (25) Haworth, *5*, **31**: 221; 08. (26) Henderson and Weimer, *81*, **13**: 469; 11. (27) Henning, *8*, **22**: 631; 07. (28) Honaman and Fonseca, *109*, **1919**: 91. (29) Meyer, *101*, **40**: 278; 19.

(30) F. W. Peek, Jr., General Electric Co., Pittsfield, Mass., *0*. (31) Peek, *B7*. (32) Peek, *107*, **76**: 1061; 20. (33) Pirani and Siemens, *9*, **15**: 969; 09. (34) Purdy, *81*, **13**: 550; 11. (35) Purdy, *81*, **15**: 499; 13. (36) Purdy and Potts, *81*, **13**: 431; 11. (37) Riddle, *38*, **2**: 804; 19. (38) Riddle, Champion Porcelain Co., Detroit, *0*. (39) Riddle and Laird, *38*, **5**: 385; 22.

(40) Riddle and Laird, *38*, **5**: 500; 22. (41) Rieke, *103*, **22**: 143; 14. (42) Rieke, *92*, **28**: 374; 15. (43) Rieke and Gary, *B5*. (44) Rosenthal, *100*, **48**: 445; 15. (45) Rosenthal and Singer, *101*, **41**: 705; 20. (46) Rosenthal and Singer, *103*, **29**: 81, 93; 21. (47) Roth, *100*, **55**: 533; 23. (48) Royal, Champion Porcelain Co., Detroit, *0*. (49) Rziha and Seidener, *B8*.

(50) Schwaiger, *101*, **43**: 875; 22. (51) J. F. Scheid, H. Schomberg and Sons, Margarethenhütte, Saxony, Germany, *0*. (52) Silsbee and Honaman, *109*, **1919**: 79. (53) Singer, *0* and *B4*. (54) Singer, *92*, **31**: 221, 227, 229; 18. (55) Singer, *112*, **9**: 96; 20. (56) Singer and Rosenthal, *104*, **1**: 3; 20. *105*, **5**: 175; 21. *100*, **54**: 250; 21. (57) Starke, *8*, **60**: 629; 97. (58) Steger, *124*, **2**: 51; 14. (59) Steger, *103*, **27**: 113; 19.

(60) Twells and Lin, *38*, **4**: 195; 21. (61) Urban, *103*, **32**: 217; 24. (62) Wagner, *125*, **3**: 67; 14. (63) Washburn and Bunting, *38*, **5**: 527; 22. (64) Waters, *32*, No. **105**; 17. (65) Watts, *81*, **11**: 84; 09. (66) Watts, *81*, **11**: 179; 09. (67) Spencer, National Lamp Works, Nela Park, Cleveland, *0*. (68) MacGee, U. S. Bureau of Mines, *0*. (69) Geller and Woods, *38*, **4**: 842; 21. (70) Grieg, *12*, **11**: 1; 26.

II. LABORATORY PORCELAINS AND WHITEWARES

JAMES A. AUDLEY[1]

A Classification of Porcelains and Whitewares Based on Their Composition and Properties

I. Body vitrified   Little or no porosity.
- (*A*) Porcelain.   More or less translucent.
  1. Hard porcelain.
     Body and glaze fired up together to a comparatively high temperature, with or without a previous low fire biscuiting. Glaze composition approximating that of the body, but with lime and often zinc oxide added.
  2. Soft porcelain.
     - (*a*) Seger porcelain.
     - (*b*) Frit porcelain.
     - (*c*) Bone porcelain.
     - (*d*) Belleek.
     - (*e*) Parian (biscuit or figure porcelain).
- (*B*) Stoneware.   Not translucent.

II. Body not completely vitrified, porous.
- (*C*) General whiteware (earthenware).
  This includes a variety of wares which pass under different trade names (semi-porcelain, white granite, etc.), but almost imperceptibly grade into one another, and into porcelain at one extreme.

Examples illustrating composition are given further on.

Wall tiles and floor tiles may be of porcelain, stoneware, or earthenware. They are made chiefly by the dry press process.

[1] Acknowledgments are due to Dr. J. W. Mellor for the free use of his library, which is rich in scientific and technical literature, and for occasional assistance kindly rendered in tracing important references.

Electrical porcelain possesses properties which give it a distinct value for certain technical purposes, so that it is impracticable to draw any hard and fast lines between it and some other porcelains. For electrical porcelains proper, *v.* p. 67.

Chemical Composition of Fired Body and Batch Composition of Raw Body

For composition limits assigned to the various types of porcelain and whiteware, *v.* the standard works such as those of Seger, Kerl, Bourry, Granger, etc., and special works such as (82, 99, 119).

The actual compositions of some of the bodies whose properties are listed in the following pages are appended hereto, together with the reference numbers by which they are identified in the subsequent pages.

BODY COMPOSITION, WT. %

Ref. No.	6	7	8	9	10	11	12	13	14	15	16	17	18
Kaolin	55	60	60	60	55	55	55	55	50	50	50	50	50
Quartz	22.5	25	20	15	30	25	20	15	35	30	25	20	15
Feldspar	22.5	15	20	25	15	20	25	30	15	20	25	30	35

Ref. No.	19	20	21	22	23	24	25	26	27	28	29	30	31
Kaolin	45	45	45	45	40	40	40	55	55	55	55	55	65
Quartz	35	30	25	20	35	30	25	40	30	22.5	15	5	25
Feldspar	20	25	30	35	25	30	35	5	15	22.5	30	40	10

Ref. No.	32	33	34*	35†	36†	37	38	39
Kaolin	65	65	25	30	35	43.4	40.5	52.0‡
Quartz	17.5	10	45	12	11	29.5	25.1	
Feldspar	17.5	25	30	60	54	25.6	29.2	42.0
$CaCO_3$						1.5	5.2	6.0

* Seger porcelain. † Figure porcelain. ‡ Sornzig kaolin.

Ref. No.	40	41	42	43	44	45	46	47	48	49
China clay	30	30	30	30	30	30	15		30	30
Ball clay	25	25	25	25	15	35	40	20	25	25
Flint	30	20	10		30	10		15		20
Feldspar	15	25	35	45	25	25	45	30	35	10
Red clay								35		
Zirconia									10	
Steatite										15

Ref. No.	50	51	52	53	54	55	56	57	58
Clay	60	65	70	65	70	75	70	75	80
Quartz	20	15	10	20	15	10	20	15	10
Feldspar	20	20	20	15	15	15	10	10	10

Ref. No.	59	60	61	62	63	64	65	66	67	68
Clay	60	55	50	45	40	60	55	50	45	40
Flint	20	22.5	25	27.5	30	25	30	35	40	45
Feldspar	20	22.5	25	27.5	30	15	15	15	15	15

Ref. No.	69	70	71	72	73	74	75	76	77	78
Clay	60	55	50	45	40	60	55	50	45	40
Flint	20	25	30	35	40	15	20	25	30	35
Feldspar	20	20	20	20	20	25	25	25	25	25

Ref. No.	79	80	81	82	83	84	85	86	87	88	89
Clay	60	55	50	45	40	35	65	40	45	50	55
Flint	10	15	20	25	30	35	10	25	20	15	10
Feldspar	30	30	30	30	30	30	25	35	35	35	35

Ref. No.	90	91	92	93	94	95	96	97	98	99	100
Clay	40	50	40	40	40	40	40	40	50	50	50
Flint	20	10	31.20	22.85	13.50	42.90	38.60	34.25	14	28.70	23.30
Feldspar	40	40	28.80	37.15	46.50	15.20	19.20	23.00	36	19.10	24.00
Whiting						1.80	2.26	2.75		2.28	2.70

Body Composition, Wt. %.—(*Continued*)

Ref. No.	101	102	103	104	105	106	107	108	109
Clay, raw	50	50	50	50	50	50	50	50	50
Clay, calcined	20	20	20	20	20	25	25	25	25
Flint	18.5	13.5	9.5	5.0		13.5	10	5	
Feldspar	10	15	19	23.5	28.5	10	13.5	18.5	23.5
Whiting	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Ref. No.	110	111	112	113	114	115
Clay, raw	50	50	50	50	50	50
Clay, calcined	30	30	30	35		
Flint	8.5	5			32.5	34
Feldspar	10	13.5	18.5	13.5	16	16
Whiting	1.5	1.5	1.5	1.5	1.5	

Ref. No.	116	117	118	119	120	121	122	123	124
Clay	71.5	77.0	80.1	85	80	80	75	75	75
Feldspar	15.6	12.5	9.5	13.5	18.5	13.5	23.5	18.5	10
Flint	2.4					5		5	13.5
Whiting	1.4	1.45	1.43	1.5	1.5	1.5	1.5	1.5	1.5
Alumina	9.1	9.05	8.97						

Ref. No.	125	126	127	128	129	130	131	132
Clay	70	70	70	80	75	70	50	50
Feldspar	23.5	19	15	10	13.5	10	16	16
Flint	5	9.5	13.5	8.5	10	18.5	32.5	34
Whiting	1.5	1.5	1.5	1.5	1.5	1.5	1.5	

Ref. No.	136	137	138	139	140	141	142
Kaolin	39	39	39	39	39	39	39
Ball clay	6	6	6	6	6	6	6
Flint	37	37	37	37	37	37	37
Feldspar	18	18	18	18	18	18	18
Whiting	3	2.5	2	1.5	1	0.5	0
Dolomite	0	0.5	1	1.5	2	2.5	3

Ref. No.	143	144	145
Kaolin	48	46	46
Quartz	18	28	33
Feldspar	34	26	21

Ref. No.	158	159	160	161	162	163	164	165
Clay substance	50	41	40	62	48	51.5	50	55
Quartz sand	22.5	54	52	33	42	43.5	42	40
Feldspar	22.5	5	5	5		5	5	5
Chalk			3		10		3	

Ref. No.	166	167	168	169	170	171	172	173	174
Clay	24*	23*	25†	22‡	24‡	23‡			
Kaolin	33	32	50	45	48	46	35	35	25
Quartz	38	37	20	22	23	23	60	60§	45
Feldspar	5	5	5		5	5	5	5	30
Chalk		3		10		3			

* Lean clay. † Fat clay. ‡ Meissen clay. § Quartz sand calcined twice at cone 15.

Bodies, Chemical Composition

Ref. No.	1*	2*	3*	4*	5†	6‡
SiO_2	60.75	69.37	74.52	79.32	70.7	67.5
Al_2O_3						26.6
TiO_2	32	23.61	2.70	18.42	23.4	0.4
Fe_2O_3						0.8
CaO	4.15	1.22	16.10	0.36	1.0	0.4
MgO	0.08	0.08	0.61			0.3
K_2O	3.02	2.58	3.45	1.82	4.8	3.3
Na_2O		2.42	2.63	0.32		0.7

Bodies, Chemical Composition.—(*Continued*)

Ref. No.	101	102	103	104	105	106	107	108	109
SiO_2	64.59	62.90	61.61	60.10	58.52	62.07	60.90	59.27	57.64
Al_2O_3	30.86	31.76	32.53	33.36	34.25	33.15	33.80	34.70	35.63
TiO_2	0.15	0.15	0.15	0.15	0.15	0.17	0.17	0.17	0.17
Fe_2O_3	0.53	0.55	0.57	0.61	0.63	0.56	0.58	0.60	0.64
CaO	1.07	1.08	1.09	1.10	1.12	1.09	1.11	1.15	1.14
MgO	0.22	0.23	0.23	0.24	0.25	0.23	0.24	0.25	0.25
K_2O	1.58	2.08	2.47	2.92	3.40	1.61	1.97	2.45	2.96
Na_2O	1.05	1.25	1.35	1.52	1.68	1.12	1.23	1.41	1.57

Ref. No.	110	111	112	113	115	133	134	135
SiO_2	59.56	58.36	56.80	55.93	72.51	72.49	71.40	75.64
Al_2O_3	35.43	36.08	37.00	38.40	22.60	22.03	27.58	22.63
TiO_2	0.18	0.18	0.18	0.19	0.16			
Fe_2O_3	0.63	0.65	0.62	0.66	0.44	3.66	0.75	0.68
CaO	1.10	1.12	1.13	1.13	1.05	Trace	0.35	0.68
MgO	0.26	0.27	0.28	0.28	0.18	0.24	0.06	0.06
K_2O	1.67	2.05	2.53	2.07	1.98		2.22	2.61
Na_2O	1.17	1.29	1.46	1.34	1.08			
Ig. loss							0.10	0.22

Ref. No.	151	152	153	154	155	156	157
SiO_2	68.4	70.00	69.52	67.65	76.45	71.27	75.02
Al_2O_3	27.7	26.21	26.56	27.74	18.90	25.24	23.40
Fe_2O_3	0.82	0.75	0.76	0.73	1.01	0.71	0.15
CaO	0.3	0.54	0.51	0.63	0.93	0.72	0.61
K_2O	1.37	1.45	1.34	1.38	0.97	1.74	
Na_2O	1.03	0.88	0.87	0.97	1.35	0.81	0.89

Ref. No.	159	160	161	162	163	164
SiO_2	74.6	72.4	60.5	62.7	68.9	67.0
Al_2O_3	17.1	16.6	25.2	19.1	20.8	20.2
Fe_2O_3	0.8	0.7	1.5	0.8	0.9	0.8
CaO	0.4	1.9	1.5	6.0	0.9	2.5
MgO			0.6	0.5	0.5	0.5
K_2O	1.7	1.7	2.2	0.5	1.2	1.2
Ig. loss	5.6	6.7	9.3	10.9	6.8	7.8

* Sèvres hard porcelain, new body, soft porcelain and stoneware, respectively, according to Coupeau (20, 21). † Limoges porcelain according to Vogt (20, 21). ‡ Berlin porcelain, general chemical composition according to Rieke (103).

Distribution of Reference Numbers (Compositions) among Literature References

Ref. No.	Lit.	Ref. No.	Lit.	Ref. No.	Lit.
1– 5	(20, 21)	36	(158, 159)	101–115	(93)
6	(18, 19, 103, 105, 129, 158, 159)	37–39	(33)	116–132	(127)
		40–49	(144)	133	(134)
		50–58	(72)	134, 135	(90)
		59–84	(74, 77, 85)	136–142	(94)
7–25	(106)			143–145	(138)
15	(56, 57)	85–91	(80, 84)	151–157	(25, 26)
16	(106, 114)	52, 69		158	(18, 19)
26–33	(112)	73–79		159–164	(42)
34	(105, 129, 158, 159)	81		165	(58)
		92–100	(76)	166–171	(88, 89)
35	(105, 129)			172, 173	(101, 102)

Petrographic Character of Laboratory Porcelains and Whiteware

The petrographic character of a ceramic body made from clay, feldspar, and flint varies according to the proportions of the component materials and also with the method of preparation (involving physical conditions) and conditions of firing. In porcelains wide variations occur in the relative amounts of glassy

matrix, undissolved quartz (or cristobalite), undecomposed or undissolved clay, and mullite ($3Al_2O_3.2SiO_2$). The mullite was for a long time regarded as sillimanite ($Al_2O_3.SiO_2$), discrimination being difficult owing to the close resemblance, *v.* p. 68.

A good porcelain of the kind indicated should consist largely of a feldspathic glassy matrix with embedded crystals of quartz and mullite distributed evenly, but no visible particles of clay. The quartz should not exceed 20, or at most 25% and the average size of its particles should not exceed 0.03 to 0.04 mm diameter, all edges and corners being rounded off through partial solution in the matrix. The crystals of mullite should be numerous and well formed, and should not exceed *ca.* 0.01 mm in length and 0.002 mm in thickness. Porcelains answering to this description can be produced only at a comparatively high firing temperature. With lower temperatures smaller proportions of glassy matrix and mullite crystals are produced, the proportions diminishing gradually until the crystals cease to be formed and the amount of glassy matrix becomes relatively insignificant, and the product is no longer porcelain but simply white earthenware.

For the microscopic characters of thin sections of porcelains and whitewares, *see* (56, 57, 67, 68, 69, 79, 90, 91, 92, 108, 150, 158, 159).

Bulk Density, Specific Gravity, and Porosity

Specific gravity	Bulk density	% open pore porosity*	% total porosity	Type	Lit.
	2.15–2.02			Bayeux hard porcelain at red to white heat	(115)
2.3 –2.5†				Hard porcelain	(29)
2.60–2.64†				*Idem.*, baked at *ca.* 950°C	(29, 103)
2.46				Berlin technical porcelain	(103)
2.46	2.32		4.4	Berlin hard porcelain	(119, 121)
2.30–2.40				Hermsdorf porcelain	(32)
	1.45–1.55			Hermsdorf porcelain, baked	(32)
2.42–2.49	2.27–2.38		4.1 – 7.9	8 commercial porcelains	(108, 118, 119)
2.49				Meissen porcelain	(123)
2.24				Sèvres porcelain	(123)
2.38				Chinese porcelain	(123)
2.44				Laboratory porcelain (Rosenthal)	(123)
2.26				Seger porcelain (Rosenthal)	(123)
2.28				Rosenthal porcelain	(123)
2.36				Japanese porcelain	(134)
2.47–2.53	2.27–2.41		3 –10	19 trial porcelains, fired at cone 12	(80)
			0.00– 1.76	6 American commercial porcelains, cone 12	(157)
		0.010– 0.034		10 trial porcelains, cone 10	(144)
		0.05 – 9.7		26 trial porcelains, cone 10	(77)
	2.35–2.39	0.02 – 0.86		3 American hotel chinas	(128)
	1.96–2.12	6.4 –11.6		4 American hotel semi-porcelains	(128)
	2.03–2.40	0.0 – 9.8		14 American hotel wares	(125)
	1.98–2.10	7.4 –10.2		8 American household wares (semi-vitreous)	(125)
	2.13–2.33	2.7 – 6.0		4 English hotel wares	(125)
	2.18–2.35	0.0		3 French and German hotel wares	(125)
2.53	2.32	0.13	8.5	Fine stoneware 538	(119)
2.45	2.23	1.80	8.9	Fine stoneware DTS sill. 54	(119)
2.45	2.28	0.19	7.7	Fine stoneware, DTS sill. 55	(119)
1.33–1.65		17.1 –21.6		6 earthenware bodies, cone 4a	(42)
2.48–2.54	2.15–2.20		11.8 –15.2	4 stonewares	(121)

* For direct determination of pore volume, *v.* (142). Different absorption methods (140).
† For effects of firing temperatures and fineness of grinding, *v.* (42, 62, 63, 80, 84, 94, 105).

Specific Gravity and Bulk Density (13)

Specific gravity	Bulk density	Type
2.628	2.363	Palissy faience
2.884	2.354	Nevers faience
2.789	2.363	Rouen faience
2.564	2.433	Creil fine faience
2.482*		Creil fine faience
2.482	2.226	English fine faience
2.567	2.455	Flemish stoneware
2.610	2.556	Japanese stoneware
2.505	2.436	English stoneware
2.569	2.508	Hard porcelain from Saxony
2.531	2.314	Bayeux hard porcelain
2.556	2.133†	Sèvres hard porcelain (1798)
2.527	2.259†	Sèvres hard porcelain (1788)
2.470	2.334	Limoges hard porcelain
2.500	2.290	Chinese hard porcelain
2.525	2.384	English soft porcelain
2.525	1.873	Sèvres soft porcelain
2.477	2.143	Tournay soft porcelain

* After firing with Sèvres hard porcelain. Specific gravities of other bodies are given in the same table. † Pores very visible.

Coefficient of Cubical Compressibility

See p. 68. *Cf.* (29, 32, 123).

Modulus of Rupture (Def. 5)

kg/cm²	Type	Lit.
774–943	Berlin technical porcelain	(107, 108, 119)
588–777	7 commercial porcelains, other than Berlin	(107, 108, 119)
420–560	Hermsdorf porcelain	(32, 113, 123)
≯690	Hermsdorf porcelain	(119)
550–670	Hermsdorf porcelain	(35)
930	A special Hermsdorf porcelain	(35)
590	Rosenthal insulator G porcelain	(113, 119, 123)
540	Rosenthal insulator H porcelain	(113, 119, 123)
640	Rosenthal table porcelain	(113, 119, 123)
410	Rosenthal laboratory porcelain	(113, 119, 123)
520	Trial porcelain 6292 (copied from American insulator porcelain)	(113, 119, 123)
106–185	6 trial earthenwares, cone 8–9, Ref. No. 159–164*	(42)
233	Faience body 135	(119)
416	Fine stoneware, DTS sill. 54	(119)
580	Fine stoneware, DTS sill. 55	(119)
980	Special trial stoneware 6412	(113, 119, 123)

Extruded cylindrical rods 16 mm diameter are fired hanging vertically, and sawn to 120 mm lengths. Loaded centrally, between steel knife edge supports, 1 kg/sec.

* Values for firings at cones 01a and 4a are also given in this paper.

Tensile Strength (Def. 4)

kg/cm²	Type	Cross section,* cm²	Lit.
1000–2000	Hard porcelain		(29)
280–363	Berlin technical porcelain	2.5 –2.9	(107, 108, 121)
161–265	7 commercial hard porcelains (other than Berlin)	2.8 –3.9	(107, 108, 119)
≯360	Hermsdorf porcelain		(119)
360–420	Hermsdorf porcelain	3.14	(35)
ca. 261	Rosenthal insulator porcelain H		(113, 123)
500	Chinese porcelain		(119)
106–887	American porcelain		(119)
258–396	19 trial porcelains, cone 15, Ref. No. 7–25		(106)
180–240	Soft porcelain, cone 8–9	3.50–3.63	(33)
184–283	Soft porcelain, cone 8–9	2.76–3.40	(33)
84–191†	10 trial porcelains fired to vitrification, cone 7–10, Ref. No. 40–49	*ca.* 3.2	(144)
108–185	6 trial earthenwares fired at cone 8, Ref. No. 166–171‡		(88, 89)
44–80	6 trial earthenwares fired at cone 8–9, Ref. No. 159–164‡		(42)
118	Special hard earthenware 237		(119)
67	Faience body 135		(119)
178	Fine stoneware DTS sill. 54		(119)
163	Fine stoneware DTS sill. 55		(119)

* The area of the cross section of the test piece is important. On comparing the tensile and crushing strengths of German and American porcelains, it may be noted that, in general, the former have greater crushing strength and the latter greater tensile strength.

† The respective values in order of the composition Ref. No. 40–49 are 125.8, 126.5, 126.5, 109.7, 123, 83.7, 92.1, 126.5, 191.2, and 141.3.

‡ Values for firings at cones 01a and 4a are also given in this paper. For other measurements of tensile strengths of trial bodies, *v.* (145). For influence of glaze, *v.* p. 68.

Crushing Strength

Unit = 1000 kg./cm²

Strength	Type	Remarks	Lit.
4–5	Hard porcelain		(14, 15, 113, 119)
4.2	Hard porcelain		(112, 123)
ca. 4.2	Berlin technical porcelain	2.5 cm cubes, determined by Rosenthal	(103)
≯5.6	Hermsdorf porcelain		(32, 119, 123)
4.8	Hermsdorf porcelain		(32, 113)
4.5 –5.5	Hermsdorf porcelain	16 mm diam., 16 mm long	(35)
2.8 –4.6	American porcelain		(119)
7.43	Porcelain 152		(119)
2.7 –4.2	8 trial porcelains, cone 16, Ref. No. 26–33*	2 cm diam. cylinders (with 3.14 cm² cross section)	(112)
2.7 –4.0	7 trial porcelains, cone 11		(94)
2.8 –4.5	6 American commercial porcelains, cone 11	Cylinders *ca.* 3.1 cm when just formed	(157)
0.04–0.08	6 trial earthenwares, cone 8†, Ref. No. 166–171		(88, 89)
5.8	Fine stoneware, DTS sill. 55		(119)

The higher values (5 and over) are probably due to the use of cylindrical instead of square test pieces. In 1920 the German Committee specified test pieces 16 mm diameter and 16 mm long.

* Highest value given by body with 55 % Zettlitz kaolin and 22.5 % each of quartz sand and feldspar. Only a little inferior were the values for bodies having 15 % feldspar and 30 % quartz, and 30 % feldspar and 15 % quartz, respectively.

† Value for firings at cones 01a and 4a are also given in this paper.

Crushing Strength between Spheres*

kg	Type	Lit.
118–152	Berlin technical porcelain	(107, 108, 119)
76–137	7 commercial hard porcelains (other than Berlin)	(107, 108, 119)
50–94	19 trial porcelains fired at cone 15, Ref. No. 7 to 25	(106)
96 (90 – 99)	Trial soft porcelain	(33)
526	Faience body 135	(119)
792	Fine stoneware, DTS sill. 54	(119)
982	Fine stoneware, DTS sill. 55	(119)

* Gary press, *v.* p. 69 (34, 107, 108). The last three values are those of the breaking load—as are some of the others given in (119) and elsewhere—and are about 10 times as large as they should be. Unfortunately, the details are not available.

Modulus of Elasticity (Def. 10)

The unit is 1000 kg/mm²

Modulus	Type	Remarks	Lit.
5.4–7.1	Hermsdorf porcelain		(29, 32, 123)
7–8	Hermsdorf porcelain		(119)
8.7–7.4	Hermsdorf porcelain		(35)
8.2–8.4	Berlin technical porcelain	Bending. Av. of 72 tests	(107, 121, 123, 131)
7.1	Sèvres hard porcelain	Fired at 1370°	(62, 63)
6.7	Sèvres new porcelain	Fired at 1270°	(62, 63)
5.0	Sèvres soft porcelain	Fired at 1100°	(62, 63)
2.5	Sèvres stoneware	Fired at 1270°	(62, 63)
3.7	Fine faience	Fired at 1270°	(62, 63)

Modulus of Elasticity (Def. 10).—(*Continued*)

Modulus	Type	Remarks	Lit.
8.4	Rosenthal insulator porcelain G and H	Bending	(123)
7.8	Rosenthal insulator porcelain G and H	Bending	(119)
9.1	Rosenthal table porcelain	Bending	(123)
8.1	Rosenthal table porcelain	Bending	(119)
8.6	Rosenthal trial porcelain 6292	Bending	(123)
14.9	Rosenthal trial stoneware 6412	Bending	(123)
8.9	Rosenthal laboratory porcelain		(119)
6.8	Rosenthal Seger porcelain 6833		(119)
6.5	Chinese porcelain		(119)
2.4	Faience body 135		(119)
5.1	Fine stoneware DTS sill. 54		(119)
6.5	Fine stoneware DTS sill. 55		(119)
151	Trial stoneware 6412		(119)

The value of the modulus changes (usually inversely) with the load. It depends less upon chemical composition than upon conditions of manufacture. It is substantially the same for tension and compression.

Modulus of Elasticity in Shear (Def. 11)

kg/cm^2	Type	Lit.
430	Trial Seger porcelain Body 6833 (Rosenthal)*	(113)
481	Rosenthal insulator Body G	(113, 119)
500	Rosenthal insulator Body H	(113, 119)
500	Rosenthal laboratory porcelain	(113, 119)
480–600	Hermsdorf porcelain	(119)
226	Fine stoneware 238	(119)
323	Fine stoneware DTS sill. 54	(119)
169	Faience Body 135	(119)
232	Special hard earthenware 237	(119)
246	Special body 240	(119)

* Square cross section.

Fixed Impact and Bending Shock (Def. 16)
Pendulum-hammer method (34, 108, 119)

$cm\text{-}kg/cm^2$	Type	Lit.
2.0	Berlin technical porcelain	(107, 108, 119, 121)
1.75–1.95	7 commercial porcelains (other than Berlin)	(107, 108, 119)
1.9	Hermsdorf porcelain	(119)
1.9–2.3	Hermsdorf porcelain	(35)
0.90	Rosenthal insulator porcelain G	(113, 119, 123)
0.95	Rosenthal insulator porcelain H	(113, 119, 123)
1.36	Rosenthal table porcelain	(113, 119, 123)
1.23	Rosenthal laboratory porcelain	(113, 119, 123)
0.08	Rosenthal trial hard porcelain 6292 (copied from American insulator porcelain body)	(113, 119, 123)
1.0	Rosenthal Seger porcelain 6833	(113, 119, 123)
2.4	Rosenthal trial porcelain 6412	(113, 119, 123)
1.61*	Rosenthal trial porcelain 6048	(113, 123)
1.76–1.95	19 trial porcelains fired at cone 15, Ref. Nos. 7–25	(106)

Fixed Impact and Bending Shock (Def. 16).—(*Continued*)

$cm\text{-}kg/cm^2$	Type	Lit.
1.23–1.8	8 trial porcelains, Ref. No. 15 considered the best	(138)
1.68–1.92	Soft porcelain, cone 8–9	(33)
1.6	Faience body 135	(119)
2.0	Hard earthenware 236	(119)
1.5	Hard earthenware 237	(119)
1.7	Earthenware 240	(119)
1.7	Fine stoneware 238	(119)
1.8	Fine stoneware DTS sill. 54	(119)
1.7	Fine stoneware DTS sill. 55	(119)
1.3–1.9	Stonewares Z58, Z59, Z60, Z61	(121)

* In (123) this value is given as 1.38, but the 1.61 occurs twice in (113).

See also (125) for a different impact test.

Successive Increasing Impact Shocks
Marten's method

112 cm × kg/cm^3 for a table porcelain (113); *see also* p. 70

Resistance to Abrasion*
Gary sand blast test, 2 min at 3 atm

Type	Loss in cm^3	Lit.
Stoneware 6412 (Rosenthal)..........	1.7	(113, 123)
Faience body 135....................	7.2	(119)
Special hard earthenware 236.........	5.8	(119)
Special hard earthenware 237.........	5.9	(119)
Fine stoneware 238..................	2.4	(119)

* In (123, p. 57) Singer quotes from (33) results for hardness obtained by Linck with the use of the sclerometer, and the corresponding values according to the hardness scale of Mohs, as follows:

	Sclerometer number	Number in Mohs scale
Easy baked porcelain......................	10–12	2
Hard baked porcelain......................	22–25	2.5
Porcelain fired to maturity, unglazed.........	550–650	7
Surface layer of glaze......................	950–1000	8
Glaze below the surface....................	350–400	6.3

Toughness and Hardness by the Rattler Test

% loss of weight by rattler test 15 min	60 min	Type Ref. No.	Lit.	% loss of weight by rattler test 15 min	60 min	Type Ref. No.	Lit.
1.93	4.62	92	(76)	4.42	8.21	70	(77)
0.68	1.95	93	(76)	2.33	5.09	71	(77)
1.57	4.33	94	(76)	2.30	4.39	72	(77)
0.30	0.88	95	(76)	1.96	4.12	73	(77)
0.58	1.97	96	(76)	5.66	10.23	74	(77)
1.17	3.31	97	(76)	5.19	8.22	75	(77)
1.73	3.46	98	(76)	2.51	5.45	76	(77)
1.95	3.70	99	(76)	2.82	5.65	77	(77)
1.96	4.95	100	(76)	5.02	8.51	79	(77)
5.36	13.94	59	(77)	4.33	8.02	80	(77)
6.10	15.36	60	(77)	3.38	6.34	81	(77)
5.18	14.73	61	(77)	2.71	4.80	82	(77)
4.77	9.32	64	(77)	2.19	4.78	83	(77)
1.06	5.54	65	(77)	1.98	4.17	84	(77)
4.03	7.43	69	(77)				

% loss of weight by rattler test 15 min	30 min	180 min	Type (94) Ref. No.	% loss of weight by rattler test 15 min	30 min	180 min	Type (94) Ref. No.
4.67	6.38	11.25	136	3.66	5.20	10.70	140
4.09	5.60	11.40	137	3.60	5.15	9.80	141
4.47	5.98	12.80	138	3.05	4.12	10.30	142
2.95	4.60	9.42	139				

The 15 min test serves to indicate the toughness or resistance to chipping.

The 180 min test indicates hardness after edges and corners have been removed.

These rattler tests were made in a ball mill 9¾ in. diameter and 13 in. long inside, making 40 revolutions per minute. The charge consisted of 61 nearly equal pebbles, weighing 22¾ lb. For each test 13 specimens of porcelain were used, which were weighed at the proper time intervals. For a standard test it is suggested that 10 kg of pebbles might be used along with 12 specimens. The above results of tests are comparable, as the same conditions were maintained throughout.

Further data relating to the rattler test with trial bodies will be found in (**53, 65, 128, 145**).

Softening Point and Cone Melting Point

°C	Type and remarks	Lit.
1500	Normal	(**122**)
1700	Special	(**122**)
1710	Rosenthal porcelain melts	(**119, 120, 123**)
1390	Japanese table porcelain, Ref. No. 133	(**134**)
1690	Porcelain, Ref. No. 134 melts	(**90**)
1670	Porcelain, Ref. No. 135 melts	(**90**)
	Berlin porcelain	
900–1000	Appreciable softening begins	(**103, 123**)
ca. 1680	Melting takes place	(**103, 119, 123**)
ca. 950	Berlin glaze softens	(**103, 123**)
Cone		
25	Berlin porcelain begins to deform	(**72**)
25	Ref. No. 58 begins to deform	(**72**)

Softening point varies with size and shape of test piece and also with time of heating, etc.

In spite of the softening of Berlin porcelain, perceptible far below 1000°C according to Rieke (**103, 123**), porcelain tubes, crucibles, etc., if suitably protected and not too severely loaded, can be safely used at temperatures up to 1400° or even higher. For Rosenthal porcelain it is claimed that when very strongly heated it can be worked like glass to make laboratory apparatus, *see* (**120**).

Rosenthal (**112**) heated one side of thick rods of different hard porcelains in an electric arc-light. He found that bodies rich in feldspar immediately split off in numerous small pieces, bodies rich in quartz and clay substance cracked off more slowly and in larger pieces, whilst specially resistant bodies merely melted at the heated places.

Coefficient of Thermal Expansion

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
3.43		23–200	(**29, 101, 102, 103, 119**)
3.53	Berlin technical porcelain, unglazed.	23–400	(**101, 102, 103, 119**)
3.55		23–600	(**101, 102, 103**)
3.56		23–700	(**29, 101, 102, 103**)
1.77		−191 to 16	(**49, 101, 102, 103, 123**)
3.36		16–250	(**49, 101, 102, 103, 123**)
3.64		16–500	(**49, 101, 102, 103, 123**)
3.77		16–750	(**49**)
4.34	Berlin porcelain	16–1000	(**49, 101, 102, 103, 119, 123**)
3.16		0–250	(**50**)
3.50		0–500	(**50**)
3.60		0–750	(**50**)
4.09		0–1000	(**50**)
ca. 4.4		>1000	(**52**)
3.76		0–625	(**51**)

Coefficient of Thermal Expansion.—(*Continued*)

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
ca. 1.79		−191 to 16	(**117, 118**)
2.94		14–56	(**117, 118**)
3.08		14–100	(**117, 118**)
2.99	Berlin porcelain	0–100	(**14, 15, 16, 17**)
3.12			(**100**)
3.8			(**119, 121**)
3.03–4.31		Various up to 1000*	(**119**)
4.25	Hermsdorf porcelain		(**119**)
3.80	Seger porcelain 6833	20–100	(**123**)
3.52	Rosenthal laboratory porcelain	20–100	(**123**)
3.60–4.79	Rosenthal elec. porcelain	0–100	(**119**)
2.69	Meissen porcelain	0–99	(**101, 102, 123, 153**)
5.4		0–1106	(**115**)*
5.3		0–1298	(**20, 21, 115**)
5.3		0–1457	(**20, 21, 115**)
6.8		0–1524	(**20, 21, 115**)
2.82–3.81		0–83	(**14, 15, 20, 21**)
2.522		0	(**101, 102, 123, 135, 136**)
2.819		20	(**135, 136**)
3.166		40	(**135, 136**)
3.265	Bayeux porcelain	50	(**101, 102, 123, 135, 136**)
3.414		60	(**135, 136**)
3.711		80	(**135, 136**)
4.008		100	(**101, 102, 123, 135, 136**)
4.305		120	(**101, 102, 123, 135, 136**)
3.53–4.07		100–600	(**1, 2, 3, 119**)
	Ref. No. 16, fired at:		
7.76	1000°C		(**110**)
5.71	1100°C		(**110**)
5.21	1250°C		(**110**)
3.97	Cone 15		(**110**)
3.74	Cone 16		(**110**)
3.72–3.60	Fired more than once		(**110**)
	Sèvres new porcelain fired at:		
5.23	1270°		(**20, 21, 25, 26**)
5.01	1370°		(**20, 21, 25, 26**)
2.99	1500°		(**20, 21, 25, 26**)
	Sèvres hard porcelain:		
5.1		0–200	(**20, 21**)
6.0	Fired at 1000°	0–400	(**20, 21**)
6.1		0–600	(**20, 21**)
5.5		0–800	(**20, 21**)
3.9		0–200	(**20, 21**)
4.3	Fired at 1370°	0–400	(**20, 21**)
4.5		0–600	(**20, 21**)
4.7		0–800	(**20, 21**)
13.5	Soft, fired at 1100°	0–200	(**20, 21**)
14.3		0–400	(**20, 21**)
5.5		0–200	(**20, 21**)
6.5	New, fired at 1000°	0–400	(**20, 21**)
8.5		0–600	(**20, 21**)
6.4		0–200	(**20, 21**)
7.0	New, fired at 1270° (normal).	0–400	(**20, 21**)
7.5		0–600	(**20, 21**)
6.9		0–800	(**20, 21**)
4.5		0–200	(**20, 21**)
4.7	New, fired at 1370°	0–400	(**20, 21**)
4.8		0–600	(**20, 21**)
4.9		0–800	(**20, 21**)
	Sèvres stoneware:		
4.5		0–200	(**20, 21**)
5.0	Fired at 1000°	0–400	(**20, 21**)
6.6		0–600	(**20, 21**)
4.8		0–800	(**20, 21**)
6.0		0–200	(**20, 21**)
7.1	Fired at 1270° (normal)	0–400	(**20, 21**)
8.6		0–600	(**20, 21**)
6.8		0–800	(**20, 21**)
9.0		0–200	(**20, 21**)
8.3	Fired at 1370°	0–400	(**20, 21**)
7.7		0–600	(**20, 21**)

* Deville and Troost made more than 200 experiments in all.

Coefficient of Thermal Expansion.—(*Continued*)

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
7.2	Fired at 1370°	0–800	(20, 21)
3.8	Limoges porcelain fired at 1370°	0–200	(20, 21)
4.2		0–400	(20, 21)
4.5		0–600	(20, 21)
4.5		0–800	(20, 21)
5.0	Fine faience (Choisy) fired at 1200°	0–200	(20, 21)
6.0		0–400	(20, 21)
7.8		0–600	(20, 21)
6.3		0–800	(20, 21)
8.1	Body of composition, $Al_2O_3 \cdot 2SiO_2$,† fired at 1250°.	0–300	(22)
7.2		0–500	(22)
6.8		0–700	(22)
6.4		0–900	(22)
7.0	Body of composition, $Al_2O_3 \cdot 10SiO_2$,† fired at 1250°.	0–300	(22)
8.2		0–500	(22)
9.8		0–700	(22)
9.3		0–900	(22)
2.9	Ref. No. 116	Room temperature to 200°	(127)
3.4	Ref. No. 117		(127)
3.1	Ref. No. 118		(127)
3.2	Ref. No. 119		(127)
2.9	Ref. No. 120		(127)
3.3	Ref. No. 121		(127)
3.5	Ref. No. 122		(127)
3.2	Ref. No. 123		(127)
4.1	Ref. No. 124		(127)
3.7	Ref. No. 125		(127)

Coefficient of Thermal Expansion.—(*Continued*)

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
3.3	Ref. No. 126	Room temperature to 200°	(127)
3.4	Ref. No. 127		(127)
4.7	Ref. No. 128		(127)
3.7	Ref. No. 129		(127)
6.1	Ref. No. 130		(127)
6.2	Ref. No. 131		(127)
4.7	Ref. No. 132		(127)
5.4	Special hard earthenware 236		(119)
7.1	Special hard earthenware 237		(119)
5.7	Fine stoneware 238		(119)
4.9	Fine stoneware DTS sill. 55		(119, 121)
4.3–4.9	4 stonewares (58–61)		(119)
	Earthenwares fired at cone 9		
ca. 10.3	Ref. No. 172, 173	22–150	(101, 102)
12.2	Ref. No. 172	220–340	(101, 102)
10.8	Ref. No. 173	220–340	(101, 102)

For other values for Berlin porcelain, *v.* (119, p. 428). For expansion coefficients of bodies with calcined clay replaced by sillimanite (mullite) or other special component, *v.* p. 70, and also (93, 127).

† Chantepie records results obtained with these two bodies fired at 1370°, and also at 1000° in the case of the former; also with bodies obtained by admixture of considerable percentages of iron oxide, feldspar, or chalk respectively with the former, and of lime or magnesia respectively with the latter. Coefficients for the range 200°–400° are also given in (127). Other thermal expansion coefficients, mainly of trial bodies, will be found in (84, 85, 146, 149). For coefficients of thermal expansion of glazes, *v.* (20, 21, 25, 26, 109).

Heat Capacity (Specific Heat)

g-cal/g°C	Range	Type	Cone	Lit.	g-cal/g°C	Range	Type	Cone	Lit.
0.258	15–912	Porcelain		(40)	0.212	20–200	Marquardt body	15	(130)
0.256	15–958	Porcelain		(40)	0.229	20–400	Marquardt body	15	(130)
0.254	15–1075	Porcelain		(40)	0.190		Porcelain, Japanese table		(134)*
0.202	20–210	Porcelain, Berlin technical	15	(103, 130)	0.17		Porcelain, hard		(32)
0.221	20–400	Porcelain, Berlin technical	15	(103, 130)	0.25		Porcelain, Rosenthal		(123, 130)†
0.212	20–200	Marquardt body	09	(130)	0.2		Porcelain, Hermsdorf		(119)
0.229	20–400	Marquardt body	09	(130)	0.185–0.187	17–100	Stonewares		(121)

* A "brown porcelain" (Japanese) used for making bottles with specific heat reported as 0.171, is evidently a stoneware.

† According to Dolazalek, the heat capacity per cm^3 is 0.575, the specific gravity being 2.3.

Average Specific Heat in Mean Calories between 20°C and

°C	100	200	300	400	500	600	700	800	900	1000	1100	Lit.
Berlin porcelain, green*	0.185	0.187	0.197	0.213	0.228							(18, 19)
Berlin porcelain, fired	0.189	0.195	0.203	0.212	0.222	0.232	0.245	0.264	0.287	0.304	0.337	(18, 19)
Berlin porcelain, glaze, green	0.170	0.174	0.183	0.193	0.208							(18, 19)
Berlin porcelain, glaze, fired	0.179	0.181	0.189	0.197	0.199	0.202	0.204	0.211	0.218	0.230	0.245	(18, 19)
Earthenware, green†	0.181	0.183	0.192	0.201	0.215							(18, 19)
Earthenware, fired	0.186	0.192	0.203	0.212	0.223	0.234	0.275	0.286	0.296	0.307	0.324	(18, 19)

* For composition, see Ref. No. 6, fired at cone 16 (1460°C).

† For composition, see Ref. No. 158, fired at cone 9.

Thermal Conductivity

Joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	BTU_{60} $ft.^{-2}$ sec^{-1} (°F, $in.^{-1}$)$^{-1}$	Type and remarks	Lit.
0.0104	0.00248 (95°)	0.00200	Porcelain	(64, 119)
0.0185	0.00442	0.00356	Japanese table porcelain	(119, 134)
0.0080	0.0019 (15°–20°)	0.00153	Rosenthal porcelain	(123)
ca. 0.00837	*ca.* 0.002	*ca.* 0.00161	Hermsdorf porcelain	(32)
0.00837–0.0167	0.002 –0.004	0.00161–0.00322	Porcelain	(29, 103)
0.0163 –0.0197	0.0039–0.0047 (165°–1055°)	0.00314–0.00379	Sèvres porcelain	(155, 156)
0 0121 –0.0222	0.0029–0.0053 (70°–1000°)	0.00234–0.00427	Stoneware	(155, 156)
0.0113	0.0027	0.00218	Fine stoneware (DTS sill.)	(121)
0.0121	0.0029	0.00234	Stoneware 58	(121)
0.0105	0.0025	0.00202	Stoneware 59, 60, 61	(121)

Resistance to Thermal Shock

No standard methods of testing have been adopted, and the recorded data therefore are not comparable; *see* (10, 11, 72, 74, 103, 120, 137, 143, 147, 148, 154).

Specific Resistivity (144)

Unit: 10^{12} ohm-cm

Temp., °C	Ref. No. 40	41	42	43	44	45	46	47	48	49
20	165	129	109	66	85	109	53	109	109	355
30	80	62	52	31	40	52	25	52	52	173
40	39	30	25	15	20	25	13	25	25	86
50	19	15	13	8	10	13	6	13	11	42
60	9.5	6.3	4.8	3.8	4.2	5.4	2.1	6.3	4.2	21
70	4.8	2.7	1.9	1.7	1.9	2.4	0.9	3.2	1.8	10
80	2.0	1.2	0.8	0.8	0.8	1.0	0.4	1.3	0.8	3.8
90	1.0	0.5	0.3	0.3	0.3	0.5	0.2	0.6	0.3	1.9
100	0.44	0.21	0.17	0.15	0.14	0.18	0.07	0.25	0.13	0.84
120	0.11	0.05	0.04	0.04	0.03	0.04	0.02	0.06	0.03	0.18
140	0.029	0.013	0.011	0.01	0.008	0.011	0.005	0.017	0.008	0.044
160	0.0083	0.0039	0.0032	0.0031	0.0033	0.0036	0.0014	0.0056	0.0024	0.0136
180	0.0028	0.0014	0.0011	0.0011	0.001	0.0012	0.0005	0.002	0.0008	0.0043
200	0.0010	0.0006	0.0004	0.0004	0.0004	0.0005	0.0002	0.0008	0.0003	0.0016

Unit: 10^{9} ohm-cm

Temp., °C	40	41	42	43	44	45	46	47	48	49
220	0.43	0.21	0.18	0.18	0.18	0.21	0.09	0.31	0.13	0.66
240	0.20	0.10	0.08	0.08	0.07	0.07	0.04	0.14	0.06	0.29
260	0.08	0.051	0.037	0.035	0.035	0.041	0.021	0.073	0.033	0.14
280	0.046	0.029	0.021	0.018	0.021	0.023	0.012	0.041	0.02	0.078
300	0.026	0.016	0.013	0.010	0.012	0.015	0.007	0.033	0.013	0.050

Volume Resistivity

Specific resist. = $A \times 10^{12}$ ohm-cm

Temp., °C	(A)	Type	Lit.
50	2150	Porcelain	(31)
100	16.1	Porcelain	(31)
150	0.416	Porcelain	(31)
200	0.134	Porcelain	(31)
210	0.00651	Porcelain	(31)
ca. 1000	0.033	Porcelain	(75)
727	0.017	Berlin porcelain	(78, 103)
20	129	Coburg porcelain	(27, 28)*
51	281	Coburg porcelain	(27, 28)
97.5	40	Coburg porcelain	(27, 28)
160.5	1.72	Coburg porcelain	(27, 28)
189	0.385	Coburg porcelain	(27, 28)
400	20	Berlin porcelain, glazed	(36)
600	3.125		(36)
800	1.818		(36)
1000	1.000		(36)
1100	0.769		(36)
400	20	Meissen porcelain, glazed	(36)
600	5.556		(36)
800	2.500		(36)
1000	1.064		(36)
1100	0.787		(36)
22	300	Chemical porcelain, unglazed	(24)
30	220		(24)
2.1	141	Hermsdorf porcelain	(43, 44)
20.5	35.5	Hermsdorf porcelain	(43, 44)
50.4	2.64	Hermsdorf porcelain	(43, 44)
59.1	1.08	Hermsdorf porcelain	(43, 44)
81.9	0.15	Hermsdorf porcelain	(43, 44)

For results of resistivity tests on a typical porcelain body (fired up to 1400°C) at temperatures ranging from 860°–1315°, *v.* (55).

* Dietrich found no essential difference between glazed and unglazed porcelain.

Temperature Coefficients of Electrical Resistance

Berlin porcelain (124)

Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$
575	−16.00	725	−2.00	875	−0.35
600	− 9.80	750	−1.60	900	−0.30
625	− 6.20	775	−1.00	925	−0.25
650	− 4.60	800	−0.70	950	−0.20
675	− 3.70	825	−0.50	975	−0.16
700	− 2.80	850	−0.40	1000	−0.12

Effect of Moisture on Electrical Resistance of Powdered Porcelain (47)

Glazed porcelain: Moisture, %	Glazed porcelain: Resistance of a cube of 1 cm edge, kilo-ohm	Unglazed porcelain: Moisture, %	Unglazed porcelain: Resistance of a cube of 1 cm edge, kilo-ohm
0.43	121 700	1.14	4 521
1.58	12 160	1.54	3 292
1.90	5 953	6.12	1 241
3.34	2 382	9.39	673.8
5.48	563.2	14.1	278.3
8.08	320.7	19.2	40.30
10.9	150.0	23.8	13.78
15.3	39.40	27.3	3.822
19.0	19.32		

Surface Resistivity

This varies enormously with humidity of the atmosphere and with the nature of the surface of the film, *see* (29, 119).

Dielectric Constant

Dielectric constant	Type	Remarks	Lit.
5.73	Berlin hard porcelain	Ref. No. 6 for composition, sp. gr., 2.38	(129, 103, 119)
6.61	Berlin Seger porcelain	Ref. No. 34, fired at cone 9, sp. gr., 2.40	(103, 129)
6.84	Berlin figure porcelain	Ref. No. 35, sp. gr., 2.41	(103, 129)
4.5–5.3	Hermsdorf porcelain		(29, 32)
5–6	Hermsdorf porcelain		(119)
5.8	Hard porcelain	Ref. No. 16, same value whether potash feldspar or soda feldspar used	(37, 114)
4.38	Baked porcelain*	"Doit être un peu fort"	(23)
8.95	Hermsdorf porcelain at 20°C		(43, 44)
5.17	Fine stoneware, DTS sill. 55		(119)

* The value is low probably because the test piece was "une plaque de porcelaine dégourdie" or product of the low biscuit firing, and therefore would be very porous.

Dielectric Strength

1. Shape of the electrodes not specified (except in ([112])). Voltage increased 0.5 kv per sec, starting at 20 kv under oil ([138])

Volts per mm	Type	Remarks	Lit.
13 200	Ref. No. 26	Test pieces, 10 cm in diam. and about 2.5 mm thick, with rounded edges, under oil. Fired at cone 16	([112])
13 800	Ref. No. 27		
14 000	Ref. No. 28		
13 200	Ref. No. 29		
12 400	Ref. No. 30		
12 800	Ref. No. 31		
13 200	Ref. No. 32		
12 400	Ref. No. 33		

2. Electrodes cup-shaped. Voltage increased 250 volts per sec, starting at 50% of the estimated puncture voltage ([144])

11 150?	Ref. No. 40	Test cups 65 and 69 mm diam. at bottom and top respectively and 65 mm in height. Minimum thickness 3 mm (middle of bottom). Firing temp. resp. cones 10+, 10, 9, 8, 9+, 9, 8, 7, 9, 7. The figures in each case represent the peak value of the puncture pressure, which was found to be 1.46 × *RMS* value of puncture pressure
13 300	Ref. No. 41	
22 650	Ref. No. 42	
32 300	Ref. No. 43	
14 300	Ref. No. 44	
27 750	Ref. No. 45	
23 000	Ref. No. 46	
16 300	Ref. No. 47	
18 400	Ref. No. 48	
15 600	Ref. No. 49	

Effect of Temperature and of Different Firing Temperatures

Volts per mm	Temp.	Type		Remarks	Lit.
11 380	24	Composition 49% mixed clays, 16% flint, 35% feldspar. Fired at cone 9 (all American materials)		Tested in elec. furnace	([48])
375	274				
17 700	25	Ref. No. 88	Fired at cone 11 or 12		
16 600	100				
7 200	200				
790	300				
17 450	25	Ref. No. 86		Test pieces were small cups (jiggered) 5½ in. high, 3 in. diam., 0.15 in. thick. At 325° all four bodies became conductors, though still offering high resistance	([152])
16 550	100				
6 560	200				
920	300				
16 800	25	Ref. No. 74			
16 250	100				
7 750	200				
1 840	300				
17 600	25	Ref. No. 76			
16 400	100				
6 950	200				
1 310	300				
13 550		Composition 59% mixed clays, 18% flint, 23% feldspar		Fired quickly to cone 10; cooled slowly	([86])
13 470				Fired quickly to cone 13; cooled to cone 02 in. one hour; then slowly	
14 660				Fired quickly to cone 10; then slowly to cone 12; quickly to cone 17; cooled slowly	
12 850				Fired quickly to cone 10; then slowly to cone 13 and fired 20 hr; cooled quickly to cone 2 and then slowly	
13 560		Composition as above but with soda-feldspar instead of potash-feldspar		Fired like the foregoing	([86])
14 820				Other bodies of different compositions gave similar results	
14 100					
13 860					

Effect of Temperature and of Different Firing Temperatures.—(*Continued*)

Volts per mm	Temp.	Type	Remarks	Lit.
25 400	14	Ref. No. 42	Test pieces were the cups described above	([144])
18 000	104			
5 030	150			
1 620	213			
1 020	248			
1 040	310*			
520	325*			

* After prolonged application of pressure. Two curves are given ([30]) showing the current-time effects of the application of a potential of 584 volts (from a storage battery) to porcelain test-pieces heated to 530°. For other tests of dielectric strength of various trial bodies refer to ([6, 71, 148]).

Velocity of Sound

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.93	Rosenthal laboratory porcelain	([113, 123])	4.9–5.2	Porcelain in general	([32, 113, 123])
6.68	Rosenthal special trial porcelain 6048	([113, 123])	3.6	Bad porcelain	([32, 113, 123])
5.05	Hermsdorf hard porcelain	([29, 113])			

The velocity of transmission of sound vibrations depends on the modulus of elasticity of the material. Hence the tone given by porcelain when struck is a function of the velocity of sound, and from such tones may be obtained indications of the quality of the porcelain.

Translucency of Porcelain

For methods and results, *v.* ([65, 74, 77, 81, 133, 151]).

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REFRACTORY MATERIALS

Gordon B. Wilkes

Typical Compositions, % by Weight

Materials	Al_2O_3	CaO	Fe_2O_3	MgO	SiO_2	Others	Lit.
Alundum	92–99						(72)
Bauxite brick	65–95		3–8		5–13	TiO_2, 1–7	(34)
Carborundum brick	0–5		0–1		0–5	SiC, 90–100	(28, 34)
Chrome brick	14–20	Trace	14–19	11–17	3–10	Cr_2O_3, 36–46	(34)
Fire clay brick	15–45	0–0.7	0–6	0–0.7	40–75	Alkalies, 0–2	(13, 34, 36, 84)
Magnesite brick	0–4	0–6	0–10	80–94	0–11	TiO_2, 0–2.8	(34, 47, 54)
Silica brick	0–2	0–6	0–2	0–0.8	90–98	Alkalies, 0–0.6	(24, 35, 40, 49, 53, 70, 86)
Zirconia brick						ZrO_2, 75–95	(74, 34, 28, 8)

Bulk Density and Specific Gravity

	Bulk density g/cm³	True sp. gr.	Lit.
Alumina, Al_2O_3		α3.93–4.01; β3.03 ± 0.01	(62, 68)
Alundum	2.6	3.02–4.00	(48, 34)
Bauxite brick		3.15–3.25	(34, 11)
Carborundum, SiC		3.12–3.20	(80)
SiC brick	2.05–2.60		(25, 80)
Chrome brick	2.8–3.2	3.90–4.00	(80, 34)
Fire clay brick	1.7–2.1	2.1–2.8	(34, 84, 18, 25)
Magnesium oxide (MgO).		α3.2; β3.67–3.69	(81, 55)
Magnesite brick	2.0–2.8	3.1–3.6	(80, 55, 34, 18, 54)
Silica, fused	2.22 (transparent); 2.07 (translucent)		(41)
Quartz, SiO_2		2.646–2.656	(48, 14)
Tridymite, SiO_2		2.31–2.32	(48)
Cristobalite, SiO_2		2.32–2.41	(46, 14)
Silica, amorphous		2.04–2.21	(48)
Silica brick	1.50–1.88	2.05–2.75	(70, 34, 18, 42, 29, 83, 86, 84)
Zirconia, ZrO_2		5.48–5.90	(48, 66, 74, 8)
Zirconia brick		4.55–5.00	(58, 74)
Carbon		1.7–2.0	(48)
Graphite		2.17–2.32	(48, 18)

Porosity

Material	Porosity, %	Lit.
Bauxite brick	46–50	(38)
Carborundum brick	17–34	(25)
Fire clay brick	20–30	(37, 84)
Magnesite brick	24–40	(42)
Silica brick	18–43	(70, 38, 42)
Zirconia brick	19	(58, 74)

Crushing Strength, Megadyne cm^{-2}

1 megadyne cm^{-2} = 14.5 lb. in.$^{-2}$ = 1020 g cm^{-2}

	20°C	800°C	1000°C	1300°C	1500°C	Lit.
Bauxite brick*	390–650	260–350	670–700	54–93	15	(4)
Carborundum*	407	417	574	147	69	(4)
Chrome brick*	442	442	417	211	74	(4)
	252		116	5.8	1.9	(51)
Fire clay brick*	191–1090	123–544	103–740	113–726	20–64	(4, 51, 84, 87)
	70–300	60–300	70–250	20–120	0–20	
Magnesite brick*	441	201	186	152	29	(4, 51, 54)
	140–600		82	64	3.5	
Silica (fused)*	2500	1020	765	164	98	(4)
Silica brick	150–200	90–170	70–160	60–110	20–80	(4, 51, 54, 57, 29, 70)
Zirconia*	388	270	338	88	9.8	(4)

* Values given by Bodin, probably high for standard brick. Test specimens were 2 cm cube.

Fusion Temperature

	°C	Lit.
Alumina, Al_2O_3	2010–2050	(8, 48)
Alundum	1750–2000	(79, 72)
Bauxite clay	1750–2000	(84, 35)
Bauxite brick	1565–1785	(44, 45)
Carborundum	2200–2240 *d*	(82, 8, 21, 72)
Chromium oxide, Cr_2O_3	1990	(44)
Chrome brick	1850–2050	(44, 54, 45, 48)
Fire clay brick	1500–1750	(44, 34, 40, 39, 45, 84)
Magnesium oxide, MgO	2800	(8)
Sintered magnesia	2200–2600	(84, 10)
Magnesite brick	2150–2165	(54, 12, 44)
Silica, SiO_2	1700–1710	(8, 44, 48)
Silica brick	1685–1800	(29, 19, 38, 48, 12, 40, 44, 45)
Mullite ("sillimanite"), $(Al_2O_3)_3(SiO_2)_2$	1816	(15)
Spinel, $MgO.Al_2O_3$	2135	(68)
Zirconia, ZrO_2	2500–2950	(8, 71, 1, 83)
Zirconia brick	2000–2600	(8, 71, 1, 74)

Temperature of Failure under Load

Load = 34.5 × 10^5 dyne cm^{-2} = 50 lb. in.$^{-2}$ = 3520 g cm^{-2}

Material	Alundum brick	Bauxite brick	Carborundum	Chrome	Fire clay	Magnesite brick	Silica	Zirconia brick
Temp. °C	1550+	1350	1650+	1400–1450	1250–1500*	1410–1555	1600–1650	1510
Remarks	No failure	Softens	No failure	Shears	Softens	Shears	Shears	Softens
Lit	(7)	(69, 7)	(52, 25)	(7, 35)	(84, 3, 19, 35)	(7)	(7, 25, 19)	(7)

* Load = 25 lb. in.$^{-2}$.

Mean Linear Coefficient of Thermal Expansion between t°C and 25°C

$$k = \frac{1}{l_{25}} \frac{l_t - l_{25}}{t - 25} = A \times 10^{-6}$$

	Variation	A 100°C	A 500°C	A 1000°C	A 1500°C	Lit.
Alumina, Al_2O_3	7.2–8.0 between 900°C and 25°C					(79)
Alundum		7.1–8.5				(79, 72)
Bauxite brick		4.4	5.2	5.3	5.3	(84)
Carborundum, SiC	4.38(800–700°C) 2.98(900–800°C)	6.58		4.35		(43)
SiC brick	6.0(1300–25°C)		5.2	5.8		(84)
Chrome brick				9.0	1.1	(48, 78)
Fire clay brick		8.1 ± 3.0	7.5 ± 3.0	6.7 ± 3.0	5.9 ± 3.0	(84, 78, 63, 55)
Mag. oxide, MgO	11.5–13.1 (300–25°C)	9.7–11.4				(23, 84)
Magnesite brick		11.5 ± 1.0	11.7 ± 2.0	12.4 ± 1.5	13.5 ± 1.0	(78, 54, 64, 50, 65, 48)
Silica brick	36 ± 3(200–25°C)	28 ± 3	22 ± 5	13 ± 2	8.6 ± 1	(78, 29, 77, 55, 53, 70, 84, 48)
Zirconia (fused), ZrO_2		8.4				(8)
Carbon			1.5–5.5			(84, 48)
Graphite	7.8(40–25°C)					(48)

For mean coefficient between any two temperatures, $\alpha_m = \dfrac{\alpha_{t_1}(t_1 - 25) - \alpha_{t_2}(t_2 - 25)}{t_1 - t_2}$, where α_{t_1} and α_{t_2} may be taken from a graph.

Expansion and Contraction during Heating

The data given in Figs. 1–4 and in the table below record the % changes in length undergone by 1 × 1 × 9 in. test bars when heated in a gas fired muffle furnace with neutral atmosphere at the rate of 100°C per hour. Specimens marked "brick" are commercial products. For compositions of these and methods of preparing all specimens, *v.* the original ([88]).

No.	Type	M. P.,* °C	Fired to, °C	$\frac{10^7 \Delta l}{l \Delta t}$ 0° to t_s	t_s,† °C
1	Silica brick	1700		83	1550
2	Kaolin	1740	1300	47	1050
3	Kaolin	1740	1430	68	1380
4	Kaolin	1740	1500	53	1580
5	Kaolin	1740	1620	43	1610
6	Fire clay brick (Mo.)	1720		54	1300
7	Fire clay brick (Pa.)	1680		51	1250
8	Fire clay brick (Colo.)	1700		54	1220
9	Fire clay brick (Md.)	1610		45	1100
10	SiC brick	>2000		43	>1700
11	Zircon white	>2000	1650	64	1510
12	Zircon brown	1935	1590	42	1550
13	ZrO_2	>2000	1675	59	1600
14	Mullite	1850	1785	53	>1700
15	Magnesite	>2000	1680	142	>1700
16	Magnesite brick			147	1440
17	Chrome brick			104	1540
18	Mg-spinel	>2000	1690	76	1600
19	Lime	>2000	1740	138	>1700
20	Fused Al_2O_3	>2000	1650	77	1580
21	Infusorial-earth brick	1630		74	1050

* Reducing atm.

† Beginning of shrinkage or expansion.

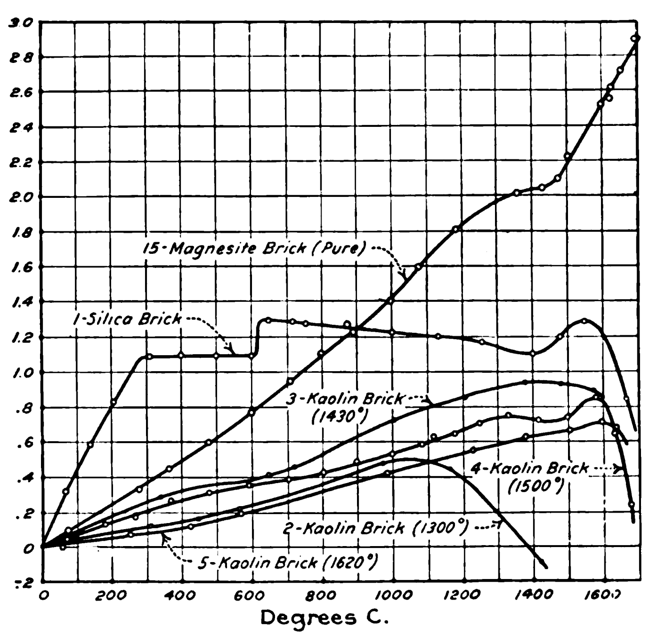

Fig. 1.

Figure 5 shows a comparison of the expansion of German and American silica brick. Curves 1, 2 and 3 are for American silica brick (measurements reported by the National Bureau of Standards); Curves I, II and III, for German silica brick (measurements by Endell and Steger, *Glastech. Ber.*, **4**; May, 1926).

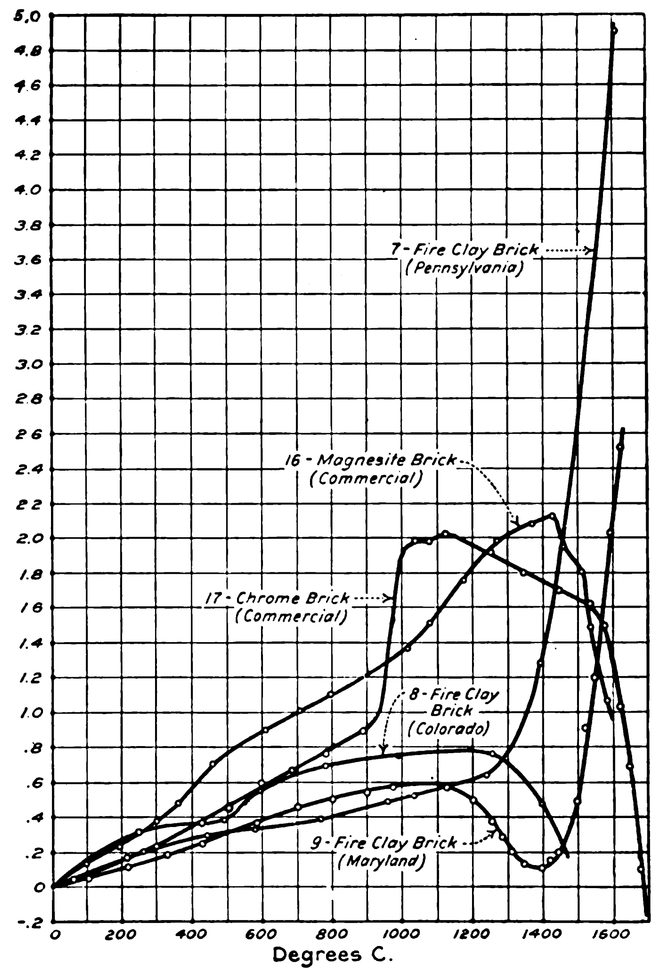

Fig. 2.

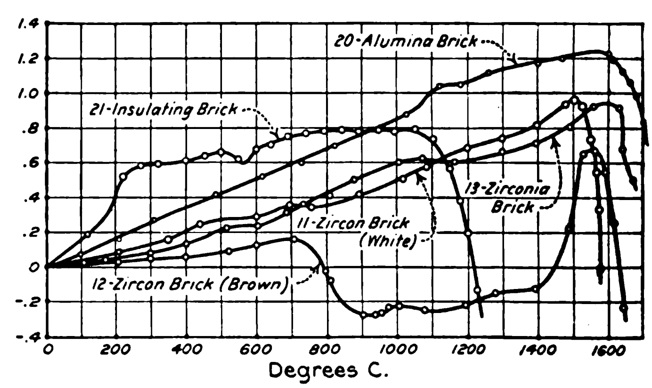

Fig. 3.

Mean Specific Heat between $t°$ and 25°C

Joule per gram per °C

1 joule g^{-1} per °C = 0.239 g-cal g^{-1} per °C = 0.239 BTU $lb.^{-1}$ per °F

	100°C	500°C	1000°C	1500°C	Lit.
Alumina, Al_2O_3	0.837	1.00	1.09	1.15	(84)
Alundum	0.778				(79)
SiC brick	0.838 ± 0.13		0.78 ± 0.17		(79, 33, 18)
Chrome brick	0.71	0.84	0.92		(78)
Fire clay brick	0.83 ± 0.04	0.93 ± 0.04	1.08 ± 0.04	1.25 ± 0.04	(78, 5, 85, 18, 31)
Mag. oxide, MgO	0.98 ± 0.02	1.09 ± 0.02	1.17 ± 0.02	1.21 ± 0.02	(84, 48, 54)
Magnesite brick	0.93 ± 0.04	1.05 ± 0.04	1.16 ± 0.04	1.24 ± 0.04	(32, 76, 84, 78, 18)
Silica brick	0.84 ± 0.06	0.95 ± 0.06	1.10 ± 0.06	1.24 ± 0.06	(5, 32, 76, 84, 61, 78, 18)
Zirconium oxide	0.46 ± 0.02	0.55	0.66	0.75	(5, 8)
Carbon	0.516	2.0 at 2000°C	1.3		(16)
Graphite		2.2 at 2000°C	1.23	1.71	(16, 46)

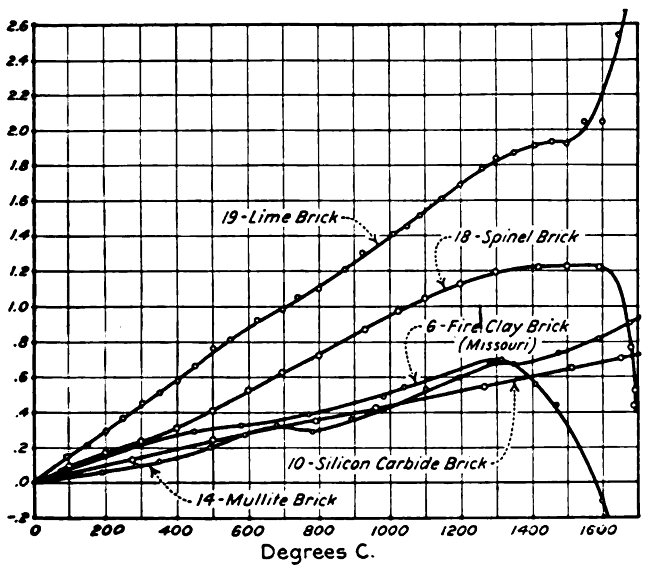

Fig. 4.

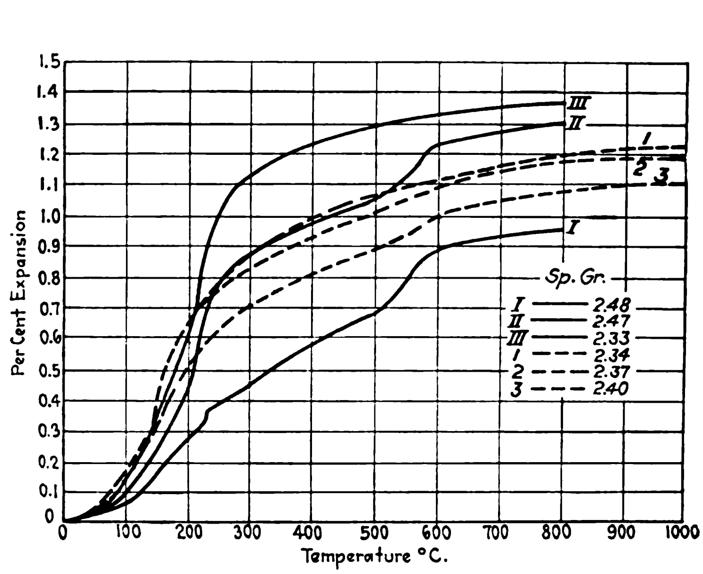

Fig. 5.

Mean Coefficient of Thermal Conductivity between $t°$ and 25°C

Joule cm^{-2}, sec^{-1} (°C, $cm^{-1})^{-1}$

1 joule cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ = 0.239 g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ = 0.193 BTU $ft.^{-2}$ sec^{-1} (°F, $in.^{-1})^{-1}$

	100°C	500°C	1000°C	1500°C	Lit.
Alundum	0.035 between 1250°C and 650°C				(62, 67)
Bauxite brick	0.0046		0.0064		(6)
SiC bonded brick			0.08–0.10		(18, 86, 79)
Chrome brick			0.024		(86)
Fire clay	0.0065 ± 0.0015	0.0089 ± 0.0015	0.0117 ± 0.0015	0.0143 ± 0.0020	(18, 22, 17, 84, 25, 31, 86)
		0.048			(84)
Magnesite bonded brick, elec. sintered	0.041 ± 0.009	0.044 ± 0.015	0.047 ± 0 020		(18, 22, 17, 84, 86)
Silica brick	0.0080 ± 0.0010	0.0096 ± 0.0010	0.0121 ± 0.0010		(18, 22, 17, 84, 16)
Carbon	0.38 at 360°C	0.45	0.55	0.58	(30)
Graphite	1.41 at 390°C	1.38	1.19	1.15	(30)

For mean coefficient between any two temperatures, $k_m = \dfrac{k_{t_1}(t_1 - 25) - k_{t_2}(t_2 - 25)}{t_1 - t_2}$ where k_{t_1} and k_{t_2} may be taken from a graph.

Electrical Resistivity

	Megohm-cm³	Ohm-cm³				Lit.
	25°C	1000°C	1200°C	1400°C	1500°C	
Alundum		1.8×10^6				(79)
Diaspore	137		193 000		2 500	(28)
Bauxite brick	133	17 200	6 100	2 200	1 100	(27)
Carborundum		3.7	1.3	0.65		(80)
Carborundum refrax brick	107×10^{-6}	4.1	2.5	1.74	1.62	(27)
Carborundum 95% SiC bonded	107×10^{-3}	4 720	4 160	1 435	745	(27)
Carborundum 90% SiC bonded	127	197 000	29 500	10 100	8 590	(27)
Chrome brick	48.1	171	63	85	41	(27)
		420	450	320		(75)
Fire clay brick	137	10 800	4 160	1 420	890	(27)
		6 600	480 000	180 000	80 000	(84)
			2 300	690	280	(75)
Magnesite brick	137	708 000	193 000	22 400	2 500	(27)
			100 000	40 000	3 000	(84)
			12 000	400		(60)
Silica (fused)	5×10^{12}	4×10^4 at 727°C				
Silica brick	125	300 000	62 000	16 500	8 420	(27)
			360 000	125 000	63 000	(84)
				2 400	710	(75)
Zirconia brick	134	131 300	1 230			(56)
			1 250	300		(1)
			7 710	968	412	(27)
Zirconia			12×10^7			(8)
Carbon	46×10^{-10}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	3.6×10^{-3} at 2000°C	(30)
Graphite	85×10^{-11}	7.95×10^{-4}	7.9×10^{-4}	7.9×10^{-4}	7.9×10^{-4} at 2000°C	(30)

For review of recent literature *v.* (89).

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ABRASIVE MATERIALS

M. L. Hartmann

COMMON AND TRADE NAMES

Ind. No.

1. Aluminium oxide (fused, impure) ("aloxite," "alundum," "lionite," "borolon," "alumo"). Al_2O_3
2. Corundum. Al_2O_3
3. Diatomaceous earth (infusorial earth, kieselguhr, fossil flour, fossil meal, tripolite, diatomite, polerschiefer, desmid earth, molera, white peat, tellurine, randanite, ceyssatite, bergmehl, radiolarian earth). SiO_2
4. Emery.
5. Flint. SiO_2
6. Garnet (almandite, rhodolite).
7. Glass (alkali lime).
8. Pumice (pumicite, santorini, santorine earth).
9. Silicon carbide ("carborundum," "crystolon," "carbolon.") SiC

For diamond, iron oxides, iron alloys and quartz, *see* other sections of I. C. T.

Ind. No.	Hardness Mohs' scale	Density g/cm³	Thermal expansion $\frac{10^6}{l}\frac{dl}{dt}$ per °C	Thermal conductivity $k = 10^{-6} \times A$ g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ A
1	9+ [25]	3.93–4.00 [3, 25]	8.7 (25–900°C) [2] 7.7 (0–1580°C) [17]	
2	9 [1, 4, 10, 11, 21]	3.95–4.10 [1, 4, 10, 21]	6.76 [19]	
3	1–1.5 [10]	2.1–2.2 [10]		227 (200°C) [10] 315 (800°C)
4	7–9 [10]	3.75–4.35 [4]		
5	7 [4,10]	2.61–2.63 [26]	17.4 (15–1000°C) [7]	
6	6.5–7 [10], *cf.* [1, 16]	3.4–4.3 [10], *cf.* [1, 16]		
7		2.4–2.6 [14]	8.01–11.88 [15]	1080–2270 [18]
8	6 [10]	2.5 [10]		
9	9–10 [9, 22]	3.17–3.21 [3, 5]	4.74 (100–900°C) [2] 4.3 (0–1700°C) [9]	43000 (1350°C) [6] (34 % porosity)

Compressibility $\frac{dV}{VdP}$ (P in atm.) = 3.8×10^{-7} for No. 2 [12]; 2.2×10^{-7} for No. 9 (100–500 atm.) [24].

Specific heat in g-cal/g = 0.1976 (8–98°C) for No. 2 [23]; 0.212–0.236 (133–405°C) for No. 7 [8]; 0.186 (31–98°C) for No. 9 [20], *cf.* [13, 27].

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PROPERTIES OF GLASS

GEORGE W. MOREY

CONTENTS.—(*Continued*)

MATIÈRES.—(*Suite*)

INHALTSVERZEICHNIS.—(*Fortsetzung*)

INDICE.—(*Azione*)

The "Index Nos." of Table 1 are identification numbers by means of which the glasses are identified in the property tables which follow.

Les nombres index de la Table 1 sont des nombres d'identification au moyen desquels les verres sont identifiés dans les tables des propriétés qui font suite.

Die Indexnummern der Tafel 1 sind Erkennungszahlen mit Hilfe deren die Gläser in den folgenden Eigenschaftstafeln identifiziert sind.

I numeri indici della Tabella 1 sono numeri di identificazione a mezzo dei quali si possono individuare i diversi vetri nelle tabelle delle proprietà.

TABLE 1.—GLASS COMPOSITIONS

With the exception of those glasses whose index numbers are in italics, all the compositions listed below are calculated from the ingredients melted to produce the glass type (so-called "batch" compositions). The glasses actually measured will therefore differ from the compositions given by unknown amounts; a difference in optical properties between the types of Table 1 and like numbered glasses in subsequent tables indicates such uncontrolled variations. The analyses of similar types shown in Table 1 give an idea of the magnitude of the difference to be expected. In the tables which follow, this uncertainty as to the actual glass composition is usually greater than that introduced by errors in measurement.

The numbers under "Glass Types" in Table 1 represent $(n_D - 1)10^3/10\nu$; in which $\nu = \frac{n_D - 1}{n_F - n_C}$. Glasses 1–114 are arranged in the order of increasing n_D; glasses 115–133, in order of decreasing SiO_2 content; glasses 134–146 in order of decreasing n_D.

TABLE 1.—COMPOSITIONS DES VERRES

A l'exception des verres dont les nombres index sont en italique, toutes les compositions indiquées ci-dessous sont calculées à partir des substances de départ entrant dans la fabrication du verre type. La composition réelle des verres dont on donne les mesures peut donc différer des compositions indiquées par un montant inconnu; une différence dans les propriétés optiques entre les types de la Table 1 et les verres de même numéro dans les tables subséquentes met en évidence ces variations incontrôlées. Les analyses de types similaires indiquées dans la Table 1 donnent une idée de l'ordre de grandeur de la différence à laquelle on peut s'attendre. Dans les tables qui suivent, cette incertitude en ce qui concerne la composition réelle du verre est ordinairement plus grande que celle introduite par des erreurs dans les mesures.

Les nombres dans "Verres types" dans la Table 1 représentent $(n_D - 1)10^3/10\nu$; dans laquelle $\nu = \frac{n_D - 1}{n_F - n_C}$. Les verres 1 à 114 sont disposés dans l'ordre de n_D accroissant; les verres 115 à 133 dans l'ordre de la teneur décroissante en SiO_2; les verres 134 à 146 dans l'ordre de n_D décroissant.

TAFEL 1.—GLAS-ZUSAMMENSETZUNGEN

Mit Ausnahme bei jenen Gläsern deren Indexnummern kursiv geschrieben sind, ist ihre folgende Zusammensetzung aus den Bestandteilen berechnet, die zur Erschmelzung des Glases verwendet worden sind (Glassatz). Die wirkliche Zusammensetzung des Glases wird deshalb von der angegebenen in unbekanntem Ausmasse abweichen. Ein Unterschied in den optischen Eigenschaften der Glastypen in der Tafel 1 und denen in den folgenden Tabellen, welche ähnlich bezeichnet sind, zeigt solche unkontrollierbare Veränderungen. Die Analyse ähnlicher Glassorten, welche in der Tabelle 1 verzeichnet sind, geben eine Vorstellung von der Grösse der Abweichungen die zu erwarten sind. In den folgenden Tabellen ist die Unsicherheit bezüglich der wirklichen Glaszusammensetzung gewöhnlich grösser, als sie durch Messfehler verursacht werden kann.

Die Zahlen unter "Glass Types" in der Tafel 1 bedeuten $(n_D - 1)10^3/10\nu$ wobei $\nu = \frac{n_D - 1}{n_F - n_C}$ ist. Die Gläser 1–114 reihen sich nach aufsteigenden n_D-Werten, Gläser 115–133 nach absteigendem SiO_2-Gehalt und Gläser 134–146 nach absteigenden n_D-Werten.

TABELLA 1.—COMPOSIZIONE DEI VETRI

Fatta eccezione per i vetri con numero indice scritto in corsivo, per tutti gli altri le composizioni riportate sono quelle che si calcolano dalle quantità dei componenti messe a fondere assieme.

Le composizioni effettive differiscono perciò da quelle indicate di una quantità sconosciuta; ed eventuali differenze nelle proprietà ottiche dei vetri della Tabella 1 e di quelli delle tabelle successive contradistinti da uno stesso numero stanno a dimostrare appunto queste incontrollatibili variazioni. Le analisi di tipi simili di vetri riportate nella Tabella 1, danno una idea della grandezza delle differenze che possono aversi. La incertezza intorno alla composizione effettiva del vetro è, in genere, maggiore di quella che può essere dovuta ad errori di misura.

I numeri sotto la dicitura "Glass Types" nella Tabella 1 rappresentano $(n_D - 1)10^3/10\nu$; dove $\nu = \frac{n_D - 1}{n_F - n_C}$. I vetri da 1 a 114 sono disposti in ordine accrescente di n_D; i vetri da 115 a 133 in ordine decrescente del contenuto di SiO_2; i vetri da 134 a 146 in ordine decrescente di n_D.

Ind. No.	Type	Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_5	As_2O_3	Cl	SO_3	H_2O	Table No.
1	475/636	Pyrex laboratory		(12)	80.75	12.00	4.10	0.10	0.30					2.20				0.40					2, 5, 11a, 11b 11c, 12a, 17a
1a		Pyrex radio																					2, 11c
2	479/702	Chance, fluor crown*	7423	(9)	54.8	18.7		20.3						0.3				0.2					11a, 11c, 13c
3	496/644	Schott, borosilicate crown	O802	(66)	71.	14	10							5.0									2, 4, 5, 7, 9, 11c
4	494/646	Schott, borosilicate crown	O2259	(55)	69.59	14	8	3.0						8.0		0.01		0.4					
5	498/653	Chance, borosilicate crown	3484	(9)	59.5	21.5		14.4	0.3		2.3			1.9				0.1					10, 13
6	500/647	Schott, borosilicate thermometer	59III	(66)	72	12	11.0							5.0									2, 7, 12b
6a		Same, analysis		(43)	72.86	10.43	9.82	0.10	0.35				0.20	6.24	Tr.	Tr.							
7	506/602	Schott, crown	O714	(68)	74.6		9.0	11.0	5.0							0.1		0.3					2, 4
8	508/604	Schott, Jena geräte		(48)	64.7	10.9	7.5	0.37	0.63		10.9		0.21	4.2	0.25	0.01		0.14					7, 12b
9	509/641	Chance, borosilicate crown	O646	(9)	69.6	6.7		20.5	2.9					0.3				0.1					13
10	510/621	Chance, borosilicate crown	4990	(9)	71.1	2.7		18.8	6.8					0.3				0.2					13
11	510/	Schott, silicate crown	O2161	(35)	69.15	1.0	6.5	15.0			11.0					0.05		0.3					10
12	511/640	Schott, borosilicate crown	O144	(68)	70.4	7.4	5.3	14.5	2.0							0.1		0.2					2, 4, 5, 7, 10, 12b, 14, 17a, 17b
12a		Same, E. T. Allen, analyst		(3)	72.15	5.88	5.16	13.85	2.04	0	0	Tr.	0.07	0.04	0.01	0		0.20	0.08	0.06	0.12	0.08	
13	511/605	Schott, borosilicate crown	O374	(68)	68.1	3.5	5.0	16.0			7.0							0.4					7
14	513/637	Schott, borosilicate crown	O627	(68)	68.2	10.0	10.0	9.5			2.0							0.2					2, 15
15	513/573	Schott, zinc silicate crown	O709	(66)	70.6		17.0				12.0							0.4					2, 4, 11b
16	515/579	Chance, zinc crown	1066	(9)	69.7		11.0	1.7	0.4		16.5			0.3				0.4					13
17	516/640	Schott, borosilicate crown, analysis	O3832	(3)	69.58	9.91	8.44	8.37	0.07	2.54	0	0	0.07	0.04	0.01	0		0.22	0.09	0.06	0.08	0.06	5, 7, 9, 11a 11c
18	516/638	Chance, borosilicate crown	6493	(9)	67.1	7.2		16.2	2.0	7.2				0.3				0.1					13
19	516/620	Borosilicate crown		(1)	67	12	9	8		4													6, 16
20	516/608	Chance, hard crown	1203	(9)	69.5			19.0	11.1					0.3				0.2					13
21	516/536	Schott, borosilicate crown	O608	(68)	53.5	20.0		6.5									20.0						2
22	517/609	Schott, borosilicate crown	O40	(68)	69.0	2.5	4.0	16.0	8.0							0.1		0.4					2, 4, 7, 11c
23	517/602	Schott, silicate crown	O60	(66)	64.6	2.7	5.0	15.0		10.2	2.0					0.1		0.4					2, 4, 7, 12b, 15, 17a
24	517/589	Schott, silicate crown	O203		Composition unknown, but probably differs but little from 23 and 25																		5, 7, 14
25	517/558	Schott, light barium crown	O1092	(53)	65.4	2.5	5.6	15.0		9.6	2.0					0.1		0.4					14, 17c
26	518/609	Bureau of Standards, light crown		(48)	68.6	3.5	12.0	5.0		9.7	1.0							0.2					7
27	518/605	Chance, hard crown	605	(9)	69.6			18.4	11.5					0.3				0.2					13
28	518/599	Bureau of Standards, light crown		(48)	67.0	3.5	12.0	5.0		10.6	1.5							0.4					7
29	519/603	Chance, hard crown	9322	(9)	72.0		6.1	10.1	11.4					0.3				0.2					13
30	520/618	Bureau of Standards, borosilicate crown		(48)	66.5	7.8	9.8	5.9		7.8	2.0							0.2					7
31	520/520	Schott, high dispersion crown	O381(1151)	(53)	68.7		15.7				2.0	13.3				0.1		0.2					11a, 14, 17c
32	522/520	Schott, high dispersion crown	O381(1250)	(68)	66.8		16.0				3.8	11.6		1.5		0.1		0.2					14
33	522/515	Schott, high dispersion crown	O381(1168)	(68)	68.2		16.5				2.0	13.1						0.2					5, 7, 11c
34	522/522	E. Posnjak, analyst	O381	(67)	67.40		15.15	0.14	0.39		3.85	10.71		1.72	0.02	0.04		0.14				0.15	
35	522/596	Schott, ordinary silicate crown	O1282	(35)	62.5	2.0	5.0	15.0		11.0	3	1.0				0.1		0.4					10
36	523/590	Ordinary crown		(1)	73.1		14.0	1.0	12.0														6, 16
37	524/522	Chance, telescope flint	4277	(9)	52.4	18.3	2.3	4.3	0.3					1.9			20.4	0.1					11a, 13
38	522/511	Schott, telescope flint	O2001		Of unknown composition, but probably differs but little from preceding																		11c, 14, 17b
39	527/546	Schott, telescope crown	O2388		Of unknown composition																		14, 17a
40	529/516	Chance, extra light flint	7863	(9)	66.8		9.2	3.9	0.4		5.2	7.1		0.3			7.0	0.1					13
41	537/512	Schott, borosilicate flint	O152(1809)	(30)	35.4	34.3	7.4					18.7	0.5	3.7									11a, 16
42	540/598	Schott, light barium flint	O227	(68)	59.5	3.0	3.0	10.0		19.2	5.0							0.3					14
42a	541/596	Same, analysis		(3)	59.13	3.04	3.16	9.70	0.13	19.25	5.00	0		0.11	0.02	0		0.34					
43	541/594	Chance, light barium crown	3463	(9)	57.1	1.8		13.7	0.3	26.9				0.2				0.1					13
44	541/469	Schott, light flint	O726		62.6		4.5	8.5		24.1								0.3					12b
45	545/503	Schott, light borosilicate flint	O658	(66)	32.75	31	1	3				25.0		7		0.06		0.25					4, 7, 10, 15, 16
46	547/458	Chance, light flint	458	(9)	59.7			12.6	0.3			26.9		0.3				0.1					13
47	549/461	Schott; extra light flint	O378	(68)	59.3		5.0	8.0				27.5						0.2					5, 7
48	549/455	Chance, light flint	1018	(9)	60.6			13.9	0.3	2.5		22.5		0.3				0.1					13
49	552/514	Chance, light barium flint	1078	(9)	56.4			12.0	0.3	15.1	4.1	11.1		0.2			0.7						13
50	552/517	Chance, light barium flint	5062	(9)	55.9			13.3	0.3	14.8	4.1	10.7		0.2			0.7						13
51	552/510	Bureau of Standards, barium flint		(48)	58.8	1.7	1.7	8.3		14.3	2.5	12.7											7
52	553/530	Schott, barium flint	O846	(68)	56.2		1.5	11.0		15.0	9.0	7.0						0.3					10, 12b, 17a

* Contains also 7.5 % F.

Ind. No.	Type	Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_5	As_2O_3	Cl	SO_3	H_2O	Table No.
53	553/461	Chance, light barium flint	7983	(9)	57.7			12.0	0.3	4.5		24.9		0.2			0.3	0.1					13
54	561/555	Schott, light barium flint	O463		Of unknown composition, but probably differs but little from 58																		5, 7, 14
55	563/429	Chance, light flint	8653	(9)	55.9			11.1	0.3			32.9		0.2				0.1					13
56	568/440	Chance, light barium flint	665	(9)	52.3			9.9	0.3	7.4		29.9		0.2				0.2					13
57	563/497	Schott, light barium flint	O543	(68)	51.6		1.5	9.5		14.0	12.0	11.0						0.3					5, 14
58	566/550	Chance, light barium flint	4469	(9)	49.3		3.2	9.5	0.3	27.2	8.6	0.7		0.2			0.8	0.1					11*c*, 13
59	568/530	Schott, light barium flint	O602	(68)	51.2		5.5	5.0		20.0	14.0	4.0						0.3					17*b*
60	571/430	Schott, light flint	O154	(68)	54.3	1.5	3.0	8.0				33.0						0.2					2, 4, 7, 11*a*, 15, 16
60a		Same, analysis		(3)	54.75	0.45	4.31	7.99	0.05	1.64	0.96	29.30	0	0.04	0.02	0		0.14	0.06	0.06		0.20	
61	572/504	Schott, light barium flint	O527	(68)	51.7		1.5	9.5		20.0	7.0	10.0						0.3					7, 15
62	573/580	Schott, light barium crown	O211	(68)	48.8	3.0	1.0	7.5		29.0	10.3							0.4					2
63	573/576	Schott, light barium crown	O211	(68)	48.1	4.5	1.0	7.5		28.3	10.1					0.1		0.1					2, 4, 5, 11*c*, 15
63a	573/574	Same, E. T. Allen, analyst		(67)	47.73	3.90	1.14	7.16	0.15	29.88	8.61		0.02	0.65	0.01			0.38		0.03	0.04	0.14	
64	573/567	Bureau of Standards, barium crown		(48)	47.6	4.0	2.0	6.0		29.2	9.9							1.4					7
65	573/420	Light flint		(1)	54		6	5				35.0											6, 16
66	574/577	Chance, medium barium crown	9002	(9)	45.6	4.4		3.9	0.3	32.5	7.9			4.9				0.6					13
67	574/570	Light barium crown		(1)	47	4	3	5		29	11			1									6, 16
68	574/571	Schott, light barium crown	O1143	(68)	47.8	4.5	1.0	7.5		28.5	10.3					0.1		0.3					14, 17*c*
69	575/414	Chance, light flint	1017	(9)	52.8			10.1	0.3			36.5		0.2				0.1					13
70	576/408	Schott, light flint	O184	(68)	53.7		1.0	8.3				36.6				0.1		0.3					5, 11*b*, 11*c*, 12*b*, 14, 17*c*
71	579/541	Schott, light barium crown	O722	(68)	48.8	3.0	0.8	6.5		21.0	15.5	4.1						0.3					5, 7, 14, 17*a*
71a	580/538	Same, analysis		(3)	45.02	4.50	0.64	6.80		22.39	15.53	4.70		0.09		0		0.55	0.06				
72	579/408	Chance, light flint	407	(9)	52.5			9.5	0.3		37.5			0.2				0.1					10, 13
73	581/442	Schott, ordinary light flint	O276	(35)	52.45		4.5	8.0			34.8					0.05		0.2					
74	581/419	Bureau of Standards, light flint		(48)	53.9		1.0	7.6	2.0			35.2						0.3					7
75	583/469	Schott, light barium flint	O578	(68)	49.1		1.0	8.5		13.0	8.5	19.3				0.1		0.5					5, 7, 10, 14, 17*b*
75a	583/463	Same, E. Posnjak, analyst		(3)	49.80		1.24	8.20		13.36	8.03	18.74		0.05	0.01	0		0.51	0.01			0.08	
76	583/466	Chance, light barium flint	466	(9)	47.5		3.0	0.91	0.3	15.3	8.3	16.3		0.2				0.1					13
77	584/561	Chance, medium barium crown	7472	(9)	42.6	5.1		9.3	0.2	31.4	10.5			0.2			0.8						13
78	585/405	Bureau of Standards, light flint		(48)	54.0		1.0	6.0	2.0			36.7						0.3					7
79	588/611	Chance, dense barium crown	9753	(9)	32.3	19.0		0.2	0.2	42.3				5.7				0.5					13
80	591/605	Schott, dense barium crown	O2122	(68)	37.5	15.0				41.0				5.0				1.5					5, 7, 14
81	604/438	Schott, barium flint	O1266	(68)	45.2			7.8		16.0	8.3	22.2				0.1		0.4					11*a*, 17*a*
82	606/440	Barium flint		(1)	46		3	4		15	8	24											6, 16
83	608/570	Dense barium crown		(1)	40	6				43	8			3									6, 16
84	610/574	Schott, heaviest baryta crown	O1029	(68)	34.5	10.1				42.0	7.8			5.0		0.1		0.5					2, 5, 11*a*, 11*c*, 14, 15, 17*a*, 17*b*
85	610/568	Same, analysis	O1209	(3)	40.17	5.96	0.13	0.03	0.03	42.35	8.17	0		2.79	0.02	0		0.49	0.03				12*b*
86	612/590	Chance, dense barium crown	4873	(9)	36.2	7.7		0.2	0.2	44.6	6.7			3.5			0.3	0.7					13
87	612/592	Schott, heaviest baryta crown	O2071	(68)	31.0	12.0				48.0				8.0				1.0					5, 7, 10
88	609/568	Same, analysis		(3)	34.56	10.96	0.21	0.09		46.91	1.14	0		5.02		0.05		0.55	0.04				
89	613/598	Chance, dense barium crown	8065	(9)	31.3	15.4		0.2	0.2	48.7				3.5			0.4	0.2					13
90	613/563	Chance, dense barium crown	2065	(9)	36.7	5.9		0.9	0.2	45.1	6.8			3.6				0.8					5, 11*a*, 13
91	613/369	Schott, ordinary silicate flint	O118	(68)	46.6		1.5	7.8				43.8						0.3					5, 7, 9, 11*a*, 11*c*, 12
91a	614/369	Same, E. T. Allen, analyst		(67)	45.64		1.77	8.66	0.05			43.45		0.03				0.22					
92	613/369	Chance, dense flint	4743	(9)	48.0		5.2	1.2	0.3			45.1		0.2				0.1					13
93	613/370	Chance, dense flint	3743	(9)	47.5		5.1	1.2	0.3			45.6		0.2				0.1					13
94	615/561	Chance, dense barium crown	1065	(9)	36.2	4.7		1.8	0.2	45.9	6.7			3.5			0.4	0.7					13
95	616/370	Medium flint		(1)	45		3	4				48											6, 16
96	621/361	Schott, ordinary silicate flint	O103	(68)	44.6		0.5	8				46.6						0.3					10, 11*a*, 11*c*, 12*b*, 14, 16, 17*b*
97	621/361	Chance, dense flint	361	(9)	46.3		5.0	1.1	0.3			47.0		0.2				0.1					13
98	627/391	Schott, baryta flint	O748	(68)	42.8		0.7	7.5		10.8	5.1	32.6						0.5					5, 7, 10, 14, 17*a*
99	632/357	Schott, ordinary silicate flint	O919	(67)	44		1	7				48											10, 17*a*
100	645/341	Schott, heavy silicate flint	O102	(66)	41			7				51.7				0.1		0.2					2, 4, 5, 16, 17*b*
100a	649/338	Same, E. Posnjak, analyst		(67)	40.99		0.61	6.93	0.13			51.13		0.04	0.02			0.22				0.08	

[redacted]		Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_3	As_2O_3	Cl	SO_3	H_2O	Table No.
101	647/337	Chance, extra dense flint	337	(9)	40.6			7.5	0.2			51.5		0.2				0.1					13
102	650/322	Schott, heavy silicate flint	O102	(82)	40.0		0.5	6.5				52.6				0.09		0.3					5, 7, 9, 11c, 14, 17c
103	655/330	Heavy flint		(1)	42		3	3				52											6, 16
104	668/356	Chance, very dense barium flint	4675	(9)	36.6			4.9	0.2	13.6	4.7	39.2		0.2			0.6	0.2					11c, 13
105	680/317	Schott, heavy silicate flint	O192	(68)	38.0			5.0				56.8				0.04		0.2					10, 16, 17a
106	717/295	Chance, very dense flint	4141	(9)	35.1			2.8	0.1			61.8		0.1									13
107	717/295	Schott, heavy silicate flint	O41	(68)	33.7			4				62.0						0.3					5, 7, 11a, 16
108	751/276	Schott, heavy silicate flint	O500	(66)	29.3			3				67.5						0.2					2, 4, 14, 16, 17c
109	755/275	Schott, heavy silicate flint	O165	(68)	28.4			2.5				69						0.1					7, 9, 15
110	756/270	Extra dense flint		(1)	28			3				69											6, 16
111	778/265	Schott, very heavy silicate flint	O198	(68)	27.3			1.5				71						0.1					5, 7, 11c
112	890/226	Schott, very heavy silicate flint	S163	(68)	22.0							78.0											14, 15, 17c
113	905/217	Schott, heaviest silicate flint	S208	(66)	20							80											2, 11a
114	963/197	Schott, heaviest silicate flint	S57	(68)	18							82											7, 14, 15, 16
115		Kavalier combustion tube		(7)	79.57		0.66	11.60	7.80				0.11	0.32	0.04								
116		Experimental glass #7	165[III]	(66)	73.8		10.5		7.0		5.0			3.5		0.2							2, 4
117		Experimental glass #34		(66)	70.2	12.0	10.3						3.0	4.5									2, 4
118		Experimental glass #90		(34)	69.5	2.0	7.0	16.0				2.5		2.5				0.4					2, 4
119		Experimental glass #87		(34)	68.2	10	10	9.5			2.0							0.2					4
120		Experimental glass #8	1419	(34)	67.9		16.8				5.8	8.1		1.0		0.1		0.3					2, 4
121		Experimental glass #84		(34)	67.7	8.0	10.0				9.0		5					0.3					4
122		Normal thermometer	16[III]	(66)	67.3	2	14		7		7			2.5		0.2							2, 4, 7, 12b
122a		Same, analysis		(43)	66.58	0.91	14.80	Tr.	7.18		6.24		0.17	3.84	Tr.	0.28							
123		Jena combustion, analysis		(7)	66.90	7.22	1.25	2.40	7.94	7.27			0.61	6.38	0.22								
124		Experimental glass #3	172[III]	(34)	64.4	12	8						11	4.5		0.1							2
125		Experimental glass #10	290	(66)	58.7			33	8									0.3					2, 4
126		Experimental glass #4	164[III]	(34)	55.0		14	14						17									2
127		Experimental glass #32		(66)	54.8			28			17							0.2					2, 4
128		Experimental glass #12	121[III]	(34)	51.3	14				25	5			4.5				0.2					2
129		Experimental glass #24		(66)	44.2		0.5	8				47				0.1		0.2					2, 4
130		Experimental glass #23		(66)	34.5	10.2				42	7.8			5				0.5					4
131				(6)	70.0		16.8				4.5	6.6		1.5		0.1		0.5					12b
132			VS1419	(6)	67.9		16.8				5.8	8.1		1.0		0.1		0.3					12b
133			O1722	(6)	69.64		17.0			5.0	5.3	2.6				0.06		0.4					12b
134	507/614	Schott, light borate crown	S205	(68)		69.1	8.0			4.7				18.0				0.2					2, 4, 7, 14, 15, 16
135	510/600	Schott, borate crown	S204	(68)		63.8	8.0	3.5		3.5		3.0		18.0				0.2					14, 17c
																			Li_2O				
136	519/609	Schott, borate crown	VS458	(68)		64.0								30					6.0				7, 11b
137	523/614	Schott	S185	(68)		71.8								22.4					5.8				2
138	573/469	Schott, borate flint	VS428	(68)		56.0						32.0		12.0									7
139	658/489	Schott, zinc borate	S665	(68)		41					59												2, 7, 14
140	666/392	Schott, borate flint	S120	(68)		42.8						52		5.0				0.2					2
					P_2O_5																		
141	516/703	Schott, light phosphate crown	O225	(68)	70.5	3.0		12.0					4.0	10.0				0.5					2, 7, 9, 15
142	522/697	Schott, light phosphate crown	S219	(66)	69.5	3.0		12.0					4.0	10.0				1.5					2
143	558/670	Schott, phosphate crown	S206	(66)	59.5	3.0				28.0				8.0				1.5					2, 4, 7, 15
144	562/646	Schott, medium phosphate crown	S179	(53)	57	3.0				37				1.5				1.5					14, 17c
																			Di_2O_3				
145	562/665	Schott, phosphate crown	S40	(51)	59.5	3.0				28				5.0				1.5	3.0				15, 7
146	567/656	Schott, phosphate crown	S95	(66)	56.0	3.0				38				1.5				1.5					2

MECHANICAL PROPERTIES OF GLASS

Density

The density of glass is dependent not only on its composition but also on its thermal history; variation in the latter factor may cause differences of ± 0.002. Figures 1–5 give the density-composition relations for a number of annealed experimental glasses. The density of four series of glasses of the general formula 100 $SiO_2 \cdot 20$ or 40 Na_2O (or 20 or 40 K_2O) $\cdot\, x$CaO can be represented by the equation $d = mx + b$, in which x = weight % CaO. Values of m, b and the range of x are: For 20 Na_2O: 0.0124, 2.368, 3.7 − 23.7 %; for 40 Na_2O: 0.0092, 2.475, 3.2 − 21 %; for 20 K_2O: 0.0097, 2.386, 3 − 22 %; for 40 K_2O: 0.0089, 2.464, 2.7 − 18.6 % [45]. The density of multicomponent commercial and experimental glasses is given in Table 2 and of optical glasses in Table 13.

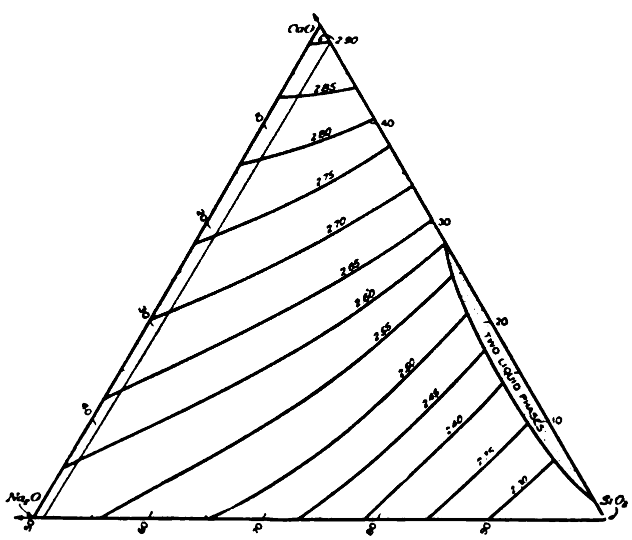

Fig. 1.—Density of the ternary Na_2O-CaO-SiO_2 glasses. Composition in weight % [41].

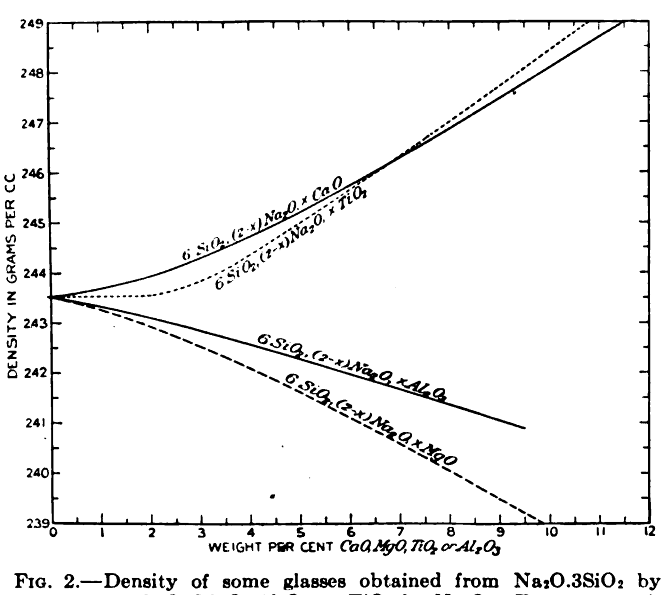

Fig. 2.—Density of some glasses obtained from $Na_2O.3SiO_2$ by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the originals [19, 20, 24, 55].

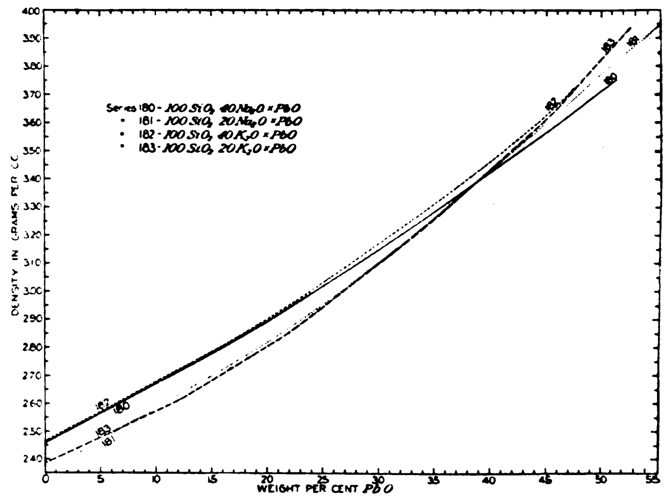

Fig. 3.—Density of some alkali-lead oxide glasses of the approximate composition shown [46].

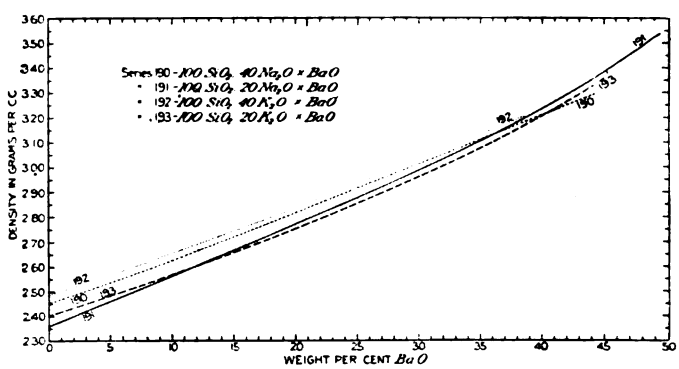

Fig. 4.—Density of some alkali-barium oxide glasses of the approximate composition shown [47].

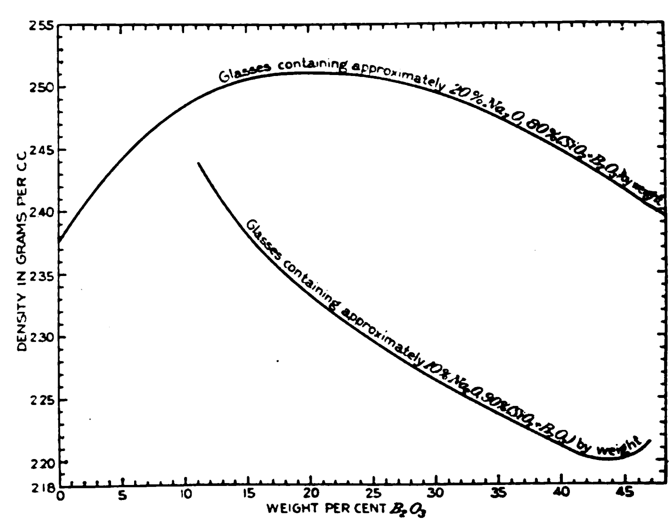

Fig. 5.—Density of some Na_2O-B_2O_3-SiO_2 glasses. Exact compositions are given in the original [28].

TABLE 2.—PROPERTIES OF SOME MULTICOMPONENT GLASSES

Serial No.	Ind. No.	Type	Density g/cm³	Young's modulus	Poisson's ratio	Tensile strength	Compressive strength	Thermal expansion $10^6 \frac{\Delta l}{l \, \Delta t}$	Specific heat g-cal/g
				Unit = 1 kilo-megabarye; 1 megabarye = 14.50 lb./in.² = 1.020 kg/cm²					
1	1	Pyrex laboratory	2.25 (12)	611(12)				3.2 (19–350°)(12)	0.20(12)
1a	*1a*	Pyrex radio						3.0	
2	3	496/644	2.370(66)	715(65)	0.197(59)	0.68(66)	12.4(66)		0.204(65)
3	6	Thermometer, 59^{III}	2.370(66)	711(65)				5.90 (0–100)(34)	
4	7	506/602	2.5 (68)	644(65)	0.221(59)				
5	12	511/640	2.47 (68)	731(65)	0.210(59)				
6	14	513/637	2.47 (68)	781(65)	0.213(59)			7.97 (17.5–94.7)(51)	
7	15	513/573	2.572(66)	637(65)	0.226(59)	0.83(66)	9.6(66)		
8	21	516/536	2.6 (68)		0.219(59)				
9	22	517/609	2.49 (68)	704(65)				8.83 (18.7–90.5)(34)	
10	23	517/602	2.580(66)	647(65)	0.231(59)	0.66(66)	9.0(66)	9.63 (17–95.5)(51)	
11	60	571/430		598(65)	0.222(59)			7.93 (12.9–97.6)(51)	
12	62	573/580	3.21 (68)					7.90 (18.9–93.1)(51)	
13	63	573/576	3.21 (68)	727(65)	0.252(59)				
14	84	610/574	3.532(66)	783(65)	0.271(59)	0.73(66)	8.3(66)		0.140(65)
15	100	645/341	3.879(66)	535(65)	0.224(59)	0.53(66)	8.3(66)		
16	108	751/276	4.731(66)	537(65)	0.239(59)	0.52(66)	6.6(66)		
17	113	905/217	5.944(66)	499(65)	0.261(59)	0.35(66)	5.9(66)	9.33 (24.5–84)(51)	
18	116	165^{III}	2.479(66)	717(65)		0.82(66)	11.1(66)		0.196(65)
19	117		2.378(66)	704(65)		0.80(66)	9.7(66)		
20	118			621(65)	0.221(59)				
21	119			782(65)					
22	120		2.629(66)	651(65)		0.66(66)	9.7(66)		
23	122	Thermometer, 16^{III}	2.585(66)	732(65)	0.228(59)			8.03 (14.6–92.2)(34)	
24	124		2.424(66)						0.209(65)
25	125		2.518(66)	589(65)	0.253(59)	0.77(66)	6.7(66)		0.189(65)
26	126		2.480(66)						0.204(65)
27	127		2.668(66)	573(65)	0.261(59)	0.81(66)	7.2(66)		
28	128		2.848(66)	709(65)				4.57 (12.69–89.8)(34)	0.162(65)
29	129		3.578(66)	528(65)		0.60(66)	7.6(66)		
		Borate glasses							
30	134	507/614	2.243(66)	461(65)	0.274(59)	0.57(66)	8.0(66)	6.71 (14.4–94.4)(51)	0.218(65)
31	137	523/614	2.238(66)		0.273(59)				0.232(65)
32	139	653/508	3.527(66)	801(65)	0.319(59)			3.33 (10.35–92.9)(51)	0.166(65)
33	140	666/392	3.691(66)						0.136(65)
		Phosphate glasses							
34	141	516/700	2.588(66)					9.30 (17.7–92.7)(51)	0.190(65)
35	142	522/697	2.588(66)	664(65)	0.235(59)	0.55(66)	7.0(66)		
36	143	558/670	3.070(66)	620(65)	0.253(59)	0.75(66)	7.4(66)	8.70 (20.3–92.2)(51)	0.159(65)
37	146	567/656	3.238(66)		0.272(59)				0.146(65)

Viscosity

For definition of viscosity see vol. 1, p. 42. The variation of viscosity with composition and with temperature in the ternary system Na_2O-CaO-SiO_2 is shown in Figs. 6–12; the effect of replacement of CaO by MgO or by Al_2O_3, in Figs. 13 and 14 respt.; and the temperature-viscosity curves of a number of experimental glasses are shown in Fig. 15 and of optical glasses in Fig. 16.

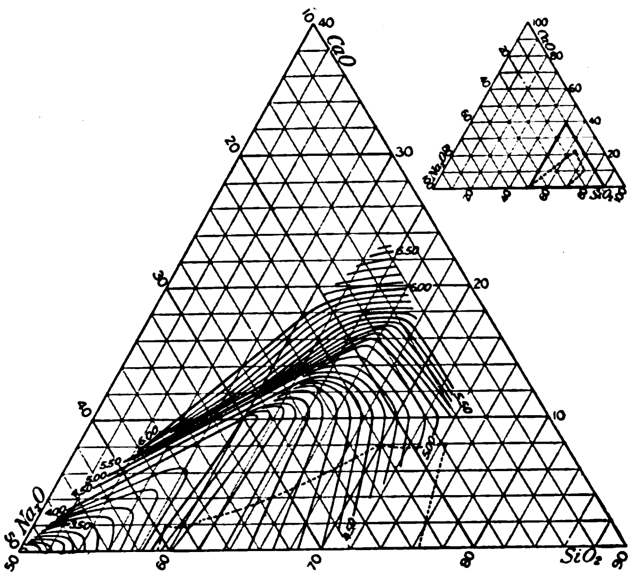

FIG. 6.—Log isokoms (lines of constant viscosity) in the system Na_2O-CaO-SiO_2, at 900°. Viscosity in log poises; composition in weight %. The broken line is the liquidus curve at 900°. *Cf.* Fig. 20 ([61]).

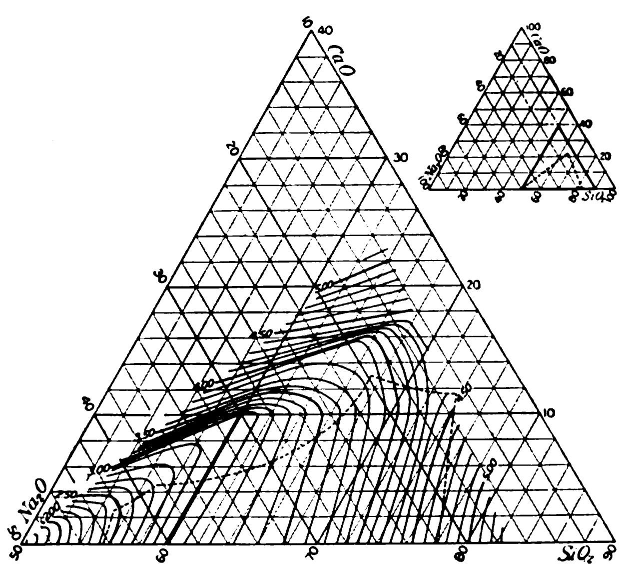

FIG. 7.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1000°. The broken line is the liquidus curve at 1000° ([61]).

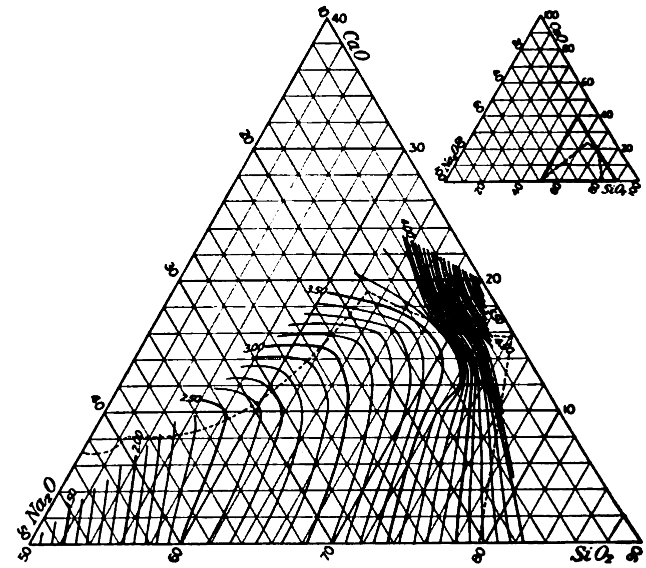

FIG. 8.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1100°. The broken line is the liquidus curve at 1100° ([61]).

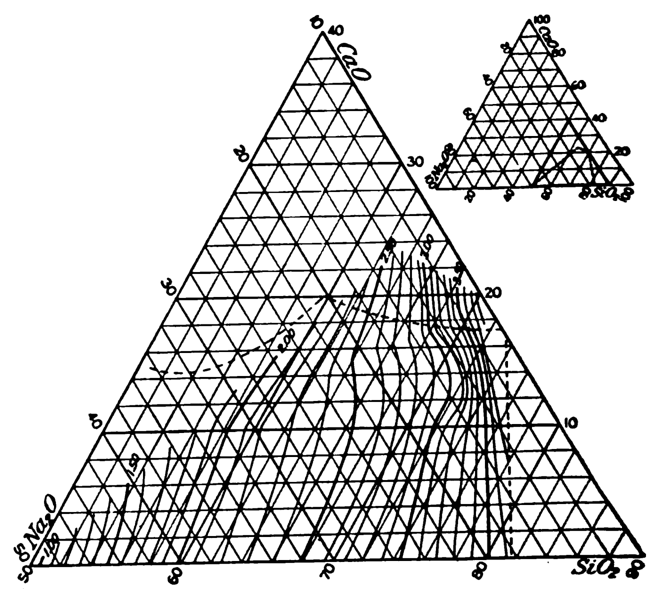

FIG. 9.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1200°. The broken line is the liquidus curve at 1200° ([61]).

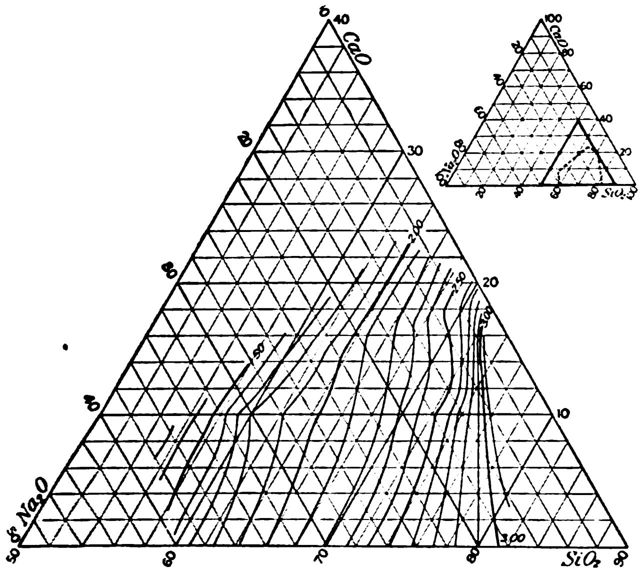

Fig. 10.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1300°. The mixtures at this temperature are all above the liquidus surface, except a few high in SiO_2 (61).

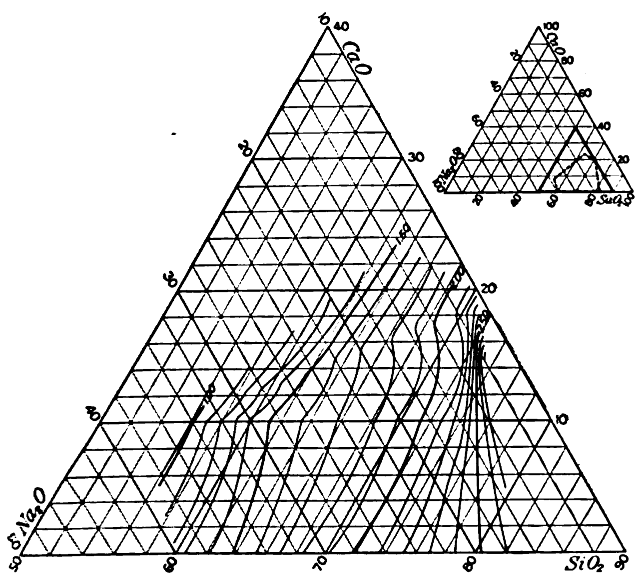

Fig. 11.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1400° (61).

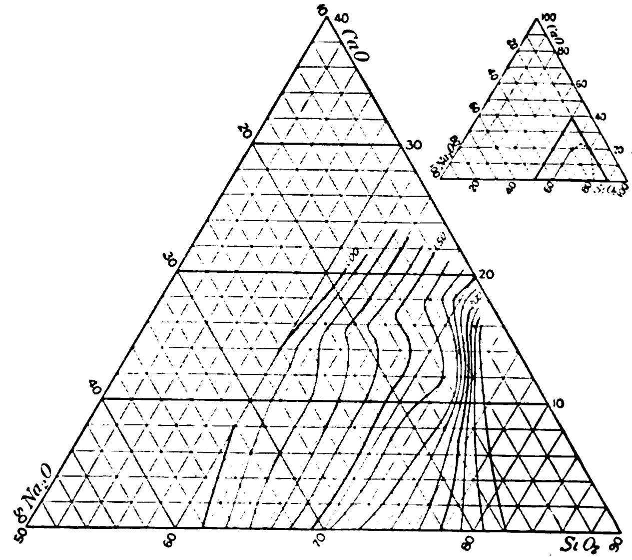

Fig. 12.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1500° (61).

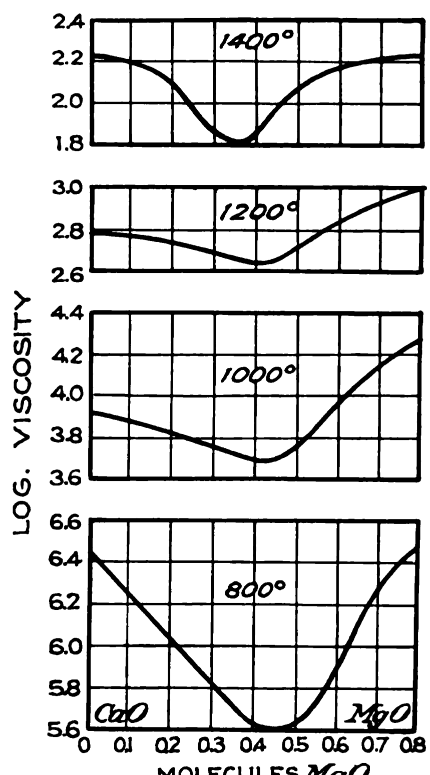

Fig. 13.—Effect on viscosity of replacing CaO by MgO in the mixture $1.2Na_2O \cdot 0.8 CaO \cdot 6SiO_2$, at different temperatures. Viscosity in poises (14.1).

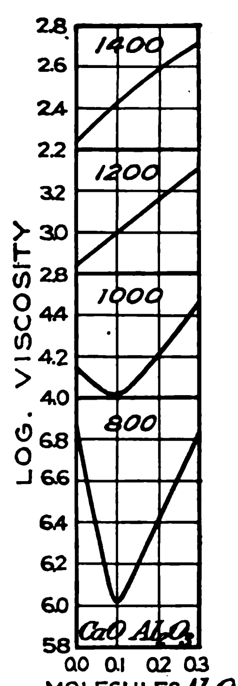

Fig. 14.—Effect on viscosity of replacing CaO by Al_2O_3 in the mixture $1.1Na_2O \cdot 0.9 CaO \cdot 6SiO_2$, at different temperatures (14.1).

Viscosity

For definition of viscosity see vol. 1, p. 42. The variation of viscosity with composition and with temperature in the ternary system Na_2O-CaO-SiO_2 is shown in Figs. 6–12; the effect of replacement of CaO by MgO or by Al_2O_3, in Figs. 13 and 14 respt.; and the temperature-viscosity curves of a number of experimental glasses are shown in Fig. 15 and of optical glasses in Fig. 16.

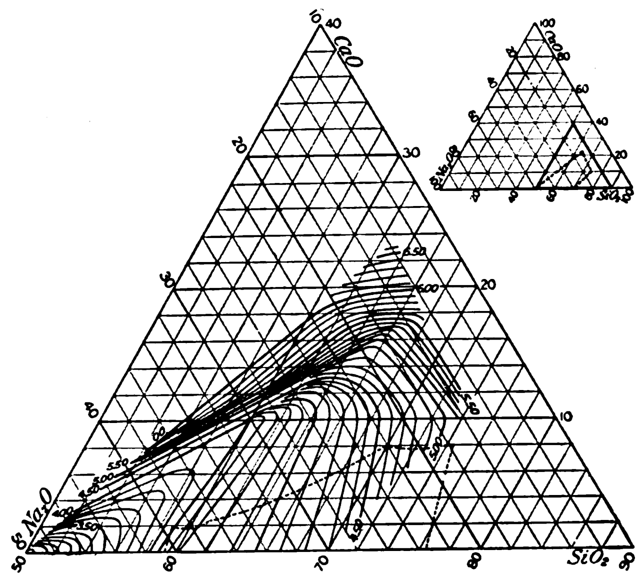

FIG. 6.—Log isokoms (lines of constant viscosity) in the system Na_2O-CaO-SiO_2, at 900°. Viscosity in log poises; composition in weight %. The broken line is the liquidus curve at 900°. *Cf.* Fig. 20 ([61]).

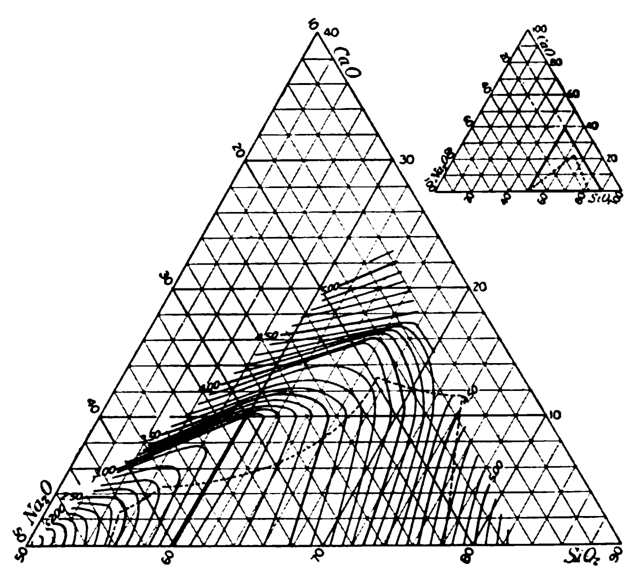

FIG. 7.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1000°. The broken line is the liquidus curve at 1000° ([61]).

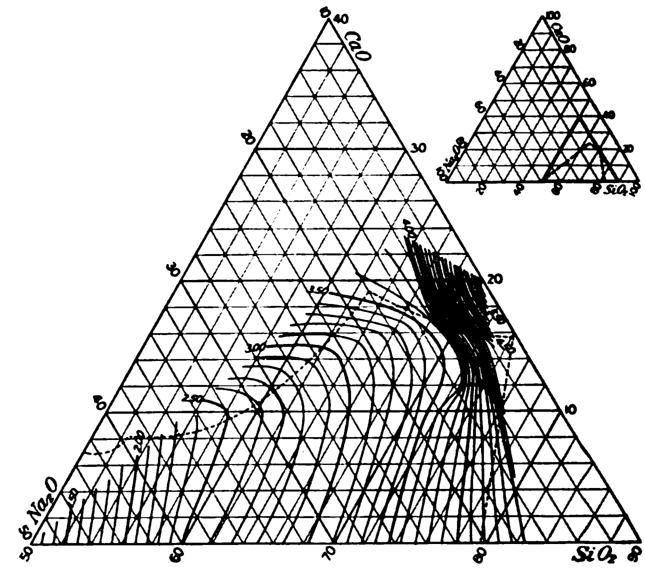

FIG. 8.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1100°. The broken line is the liquidus curve at 1100° ([61]).

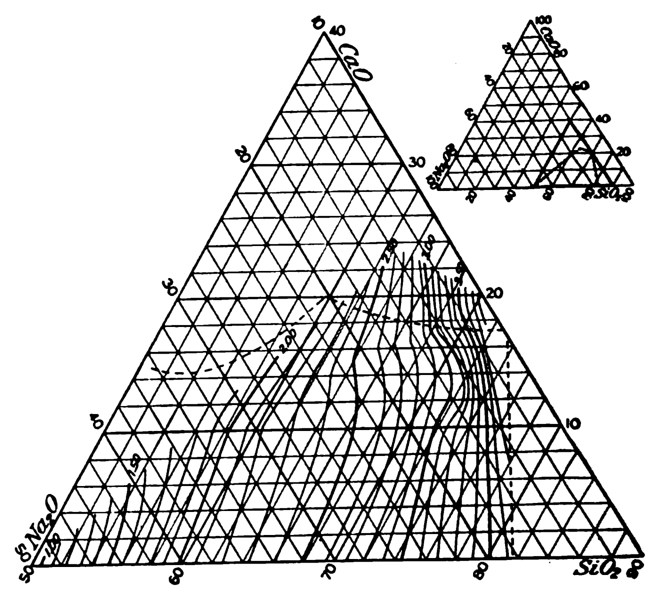

FIG. 9.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1200°. The broken line is the liquidus curve at 1200° ([61]).

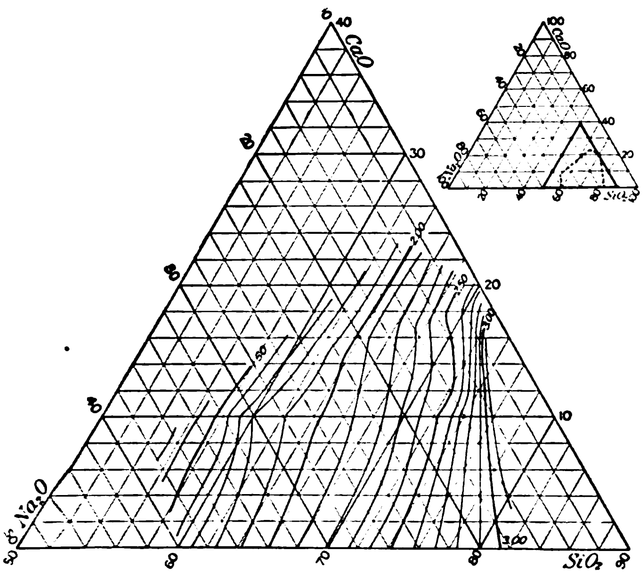

FIG. 10.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1300°. The mixtures at this temperature are all above the liquidus surface, except a few high in SiO_2 (61).

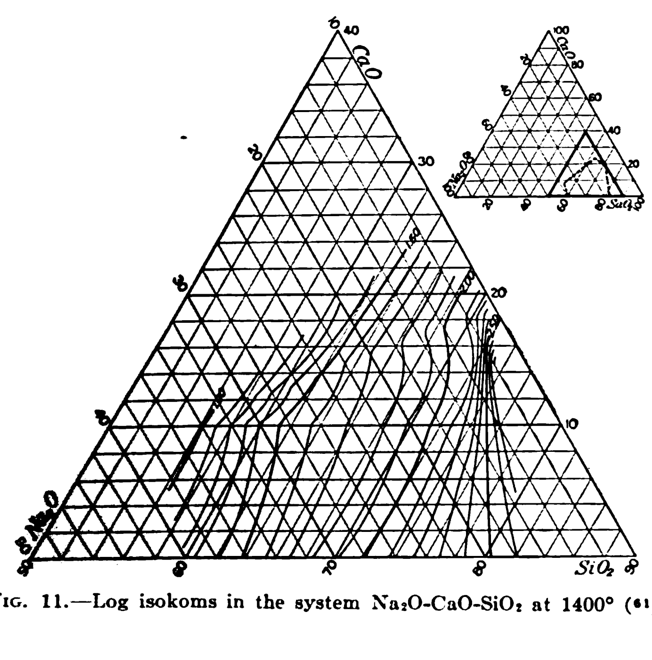

FIG. 11.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1400° (61).

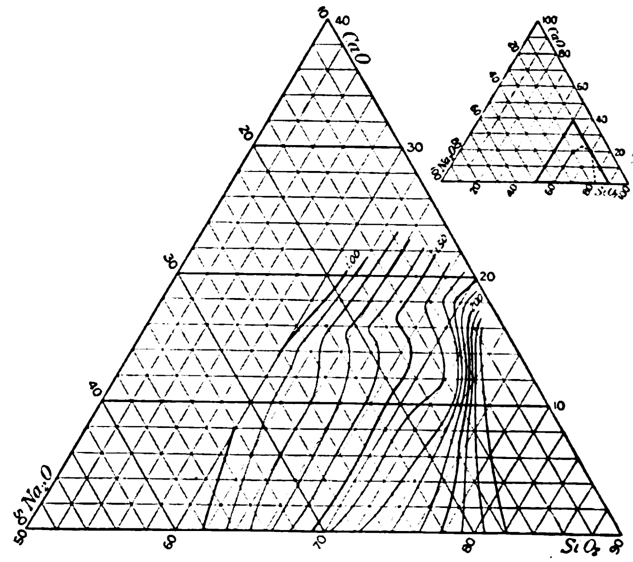

FIG. 12.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1500° (61).

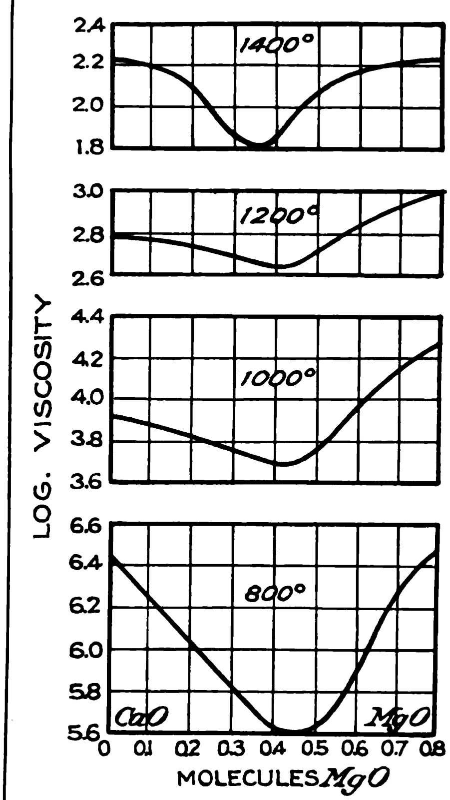

FIG. 13.—Effect on viscosity of replacing CaO by MgO in the mixture $1.2Na_2O \cdot 0.8 CaO \cdot 6SiO_2$, at different temperatures. Viscosity in poises (14.1).

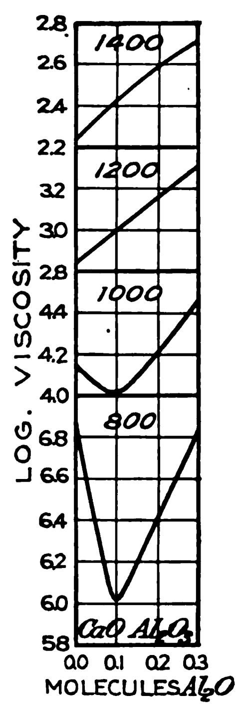

FIG. 14.—Effect on viscosity of replacing CaO by Al_2O_3 in the mixture $1.1Na_2O \cdot 0.9 CaO \cdot 6SiO_2$, at different temperatures (14.1).

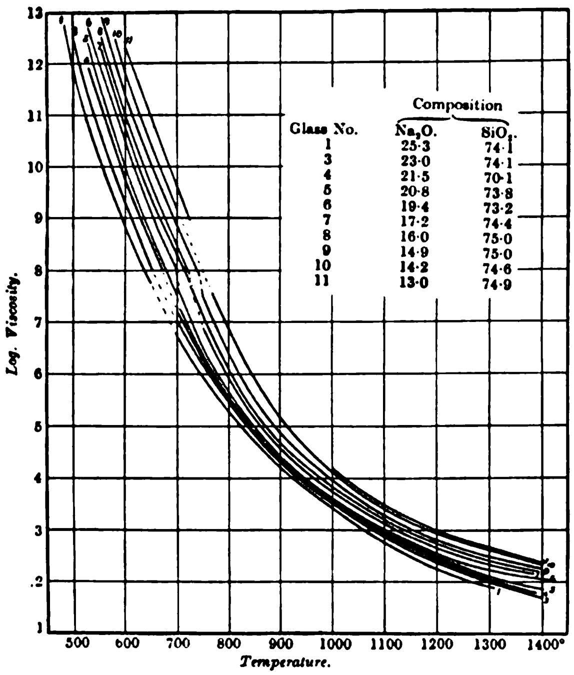

FIG. 15.—Variation of log viscosity, in poises, with temperature, of a number of experimental glasses ([14]).

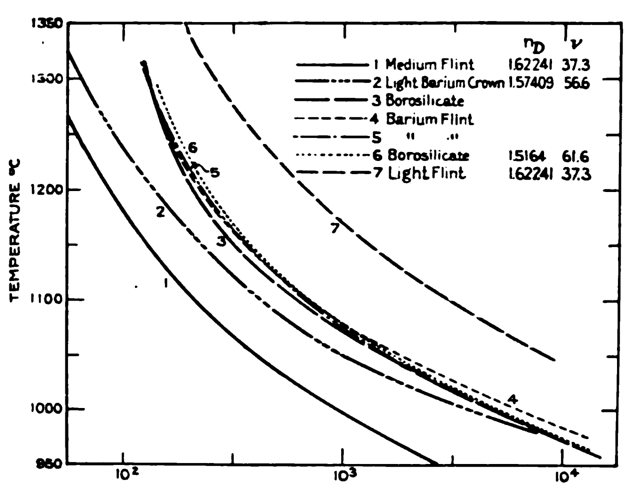

FIG. 16.—Variation of viscosity with temperature in a number of optical glasses ([61.1]).

Surface Tension

The variation of surface tension with composition in the ternary Na_2O-CaO-SiO_2 glasses at constant temperature is shown in Figs. 17 and 18; the variation with temperature in Fig. 19.

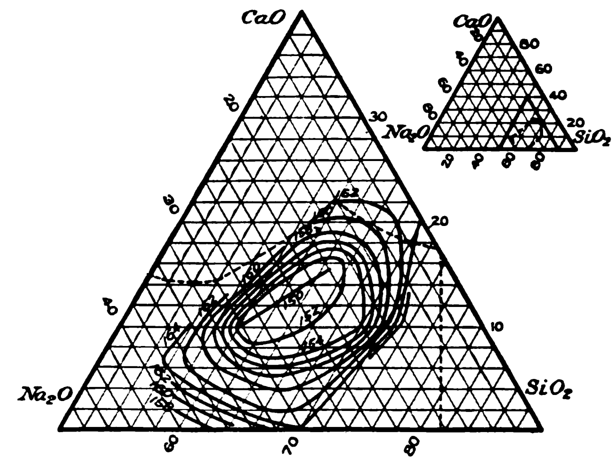

FIG. 17.—Surface tension of Na_2O-CaO-SiO_2 mixtures at 1206° ([61]).

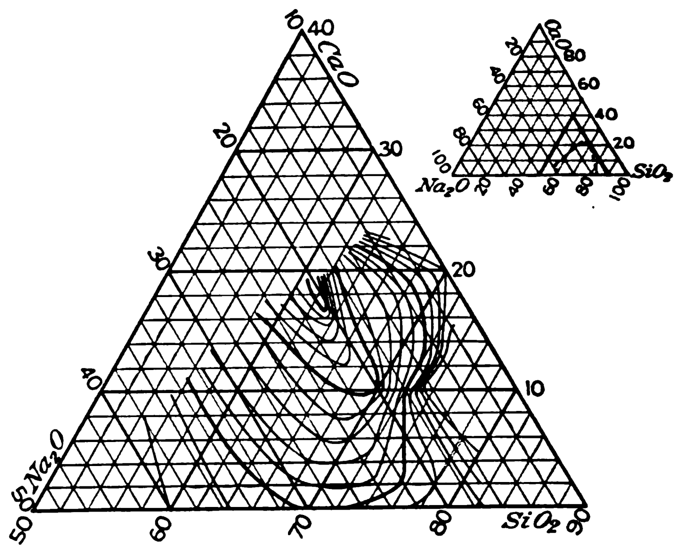

FIG. 18.—Surface tension of Na_2O-CaO-SiO_2 mixtures at 1454° ([61]).

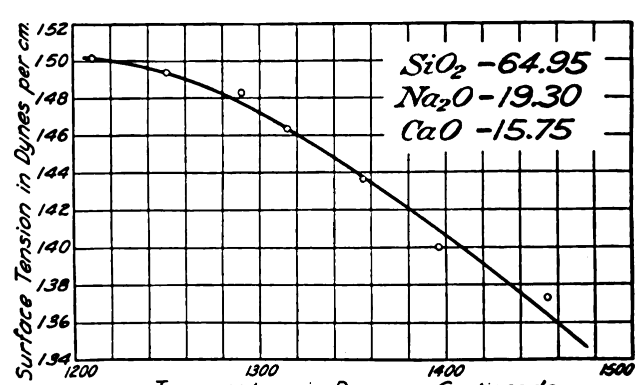

FIG. 19.—Variation of surface tension with temperature ([61]).

Strength

The strength of glass is so greatly influenced by its thermal history ([33]) and the condition of its surface ([38]) that the values given are of uncertain significance and should be used only with an ample factor of safety.

Values of tensile and compressive strength of a number of glasses are given in Table 2. The strength of glass fibers as a function of thickness is given by Griffith ([33]). The following summarizes the data for tubes, determined on a glass of unknown composition.

TABLE 3.—BURSTING STRENGTH OF GLASS TUBES ([44])

Maximum fiber stress, T_m, calculated from the formula

$$T_m = \frac{1}{4}\left[5P_m + 7\left(\frac{P_m - 1}{\left(\frac{R}{R'}\right)^2 - 1}\right) - 1\right] \text{(unit = } 10^6 \text{ barye)}$$

Shape of tubes	Range of radii, R, mm		Number tubes tested	Range of bursting pressures, P_m	Max. fiber stress, T_m	Mean var. from mean, %
	External, R	Internal, R'				
Thick walled..	9–18	3–6	9	230–380	470	14
Capillary.....	5–7	0.24–1.0	16	420–1200	902	27
Thin walled..	3.8–7.8	3.4–7.3	17	54–377	628	20

Elastic Properties

Young's modulus, E, and Poisson's ratio, σ, for a number of commercial and experimental glasses are given in Table 2; the rigidity and bulk moduli, C and K, are related to these through the equation $C = E/2(1 + \sigma)$ and $K = E/3(1 - 2\sigma)$. The variation of E, in kilo-megabaryes, with weight % of CaO is given by the equation $E = 13.9y + 565.6$, in the range 0–11% CaO ([10a]). The variation of Young's modulus with temperature is shown in Table 4.

TABLE 4.—THE EFFECT OF TEMPERATURE ON ELASTICITY ([66])

$E_t = E_{20}\,[1 - \alpha(t - 20)^\beta]$; range, room temp. to $t_{max.}$ (unit: 10^9 barye)

Ind. No.	Glass Type	$E_{20°}$	$\log_{10}\alpha$	$\log_{10}\beta$	$t_{max.}$
3	496/644	752	$\bar{9}.018$	0.428	482
7	506/602	655	$\bar{4}.618$	0	448
12	511/640	740	$\bar{4}.352$	0	475
15	513/573	684	$\bar{5}.912$	0.065	409
22	517/609	709	$\bar{4}.369$	0	433
23	517/602	654	$\bar{4}.575$	0	394
45	545/503	549	$\overline{15}.452$	0.706	383
60	571/430	609	$\overline{10}.973$	0.499	374
63	573/575	744	$\bar{6}.923$	0.165	427
100	645/341	540	$\overline{24}.492$	0.945	340
108	751/276	539	$\bar{8}.634$	0.401	357
116		738	$\bar{5}.543$	0.082	460
117		721	$\bar{5}.114$	0	482
118			$\bar{4}.616$	0	434
119		817	$\bar{4}.248$	0	447
120		652	$\overline{15}.401$	0.717	433
121		741	$\overline{11}.092$	0.553	407
122		730	$\bar{6}.435$	0.232	426
125		604	$\bar{5}.696$	0.113	455
127		577	$\bar{4}.193$	0	417
129		532	$\overline{13}.897$	0.643	413
130		798	$\bar{5}.330$	0.094	486
134	507/614	492	$\bar{4}.449$	0	281
143	558/670	631	$\bar{6}.230$	0.255	412

THERMAL PROPERTIES OF GLASS

Melting Point Diagrams

The melting point diagrams showing the compositions of the crystalline solid phases which may exist in equilibrium with liquid and the relation between equilibrium temperature and composition of that liquid are not known for most of the glass-forming systems. Figures 20 and 21 give these for the ternary system $Na_2O \cdot SiO_2$-$CaO \cdot SiO_2$-SiO_2 and the binary system PbO-SiO_2.

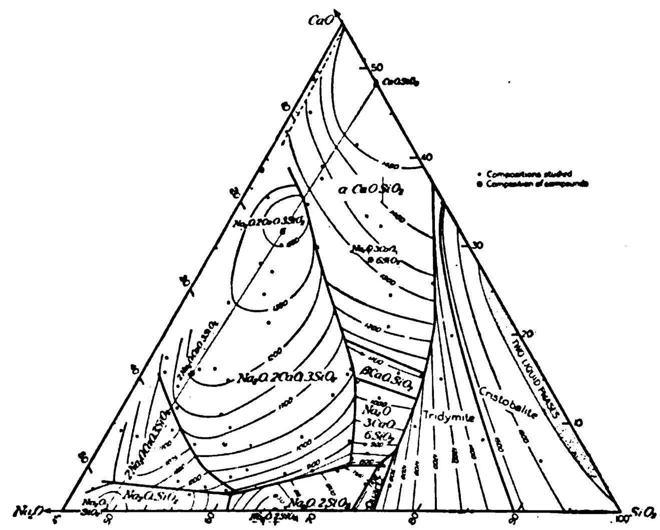

FIG. 20.—Melting point diagram of the system Na_2O-CaO-SiO_2. Composition in weight % ([39]).

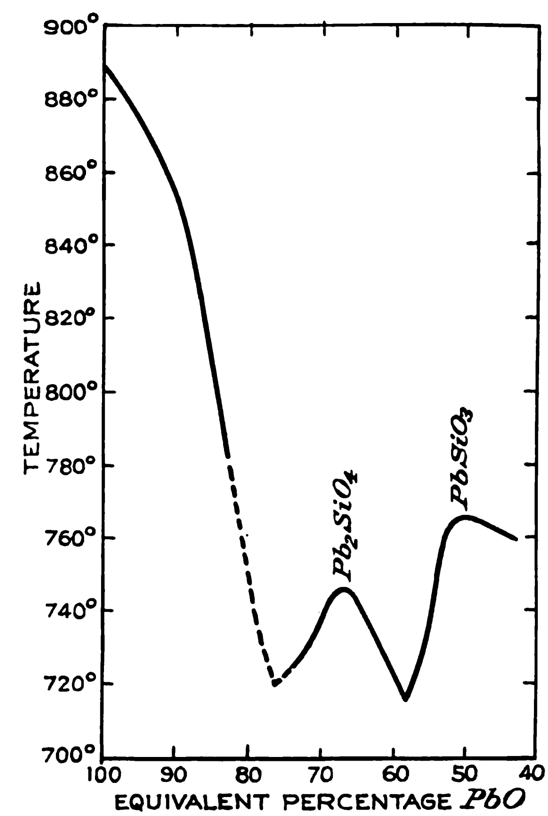

FIG. 21.—Melting point diagram of the system PbO-SiO_2 ([11]).

Table 5.—Thermal Constants of Representative Glasses

Glasses are undercooled liquids, and hence have no melting points. Following are some of the empirical definitions that have been proposed for characterizing glasses as to their thermal behavior, and the corresponding temperatures for some representative glasses. (*a*) Annealing temperature ([62]): the temperature at which the ratio of final to initial strain is a minimum, when heating and cooling are carried out in a prescribed manner; *v. also* Table 6 and Figs. 22, 23 and 24. (*b*) Deformation temperature ([62]): the lowest temperature at which, after 6 hr, one observes a deformation of the polished faces of a 20 mm cube embedded in kieselguhr with a diagonal vertical. (*c*) Cohesion temperature ([69]): the lowest temperature at which 2 plane polished pieces, 2 mm thick, 10 mm diameter, will coalesce in 30 min. (*d*) Softening temperature, for pyrex ([12]): the temperature at which a rod 9 in. long and 0.6 mm diameter lengthens under its own weight at the rate of 1 mm per min when heated in an electric furnace throughout its upper 9.5 cm of length. For the rest of the glasses ([69]), the constant t_o in the empirical 3-constant equation $(t_o - t)(S + S_o) = C$, expressing the relation between the stress, S (measured by birefringence), produced by quickly cooling a cm cube from the temperature t. (*e*) Flow temperature ([63]): the temperature at which a 25 mm cube embedded in kieselguhr with diagonal vertical flows until the corner cannot be detected, in the given time.

Table 5.—Constantes thermiques des verres représentatifs

Les verres sont des liquides surfondus, et par conséquent ne possèdent pas de point de fusion. Dans ce qui suit, on trouvera quelques-unes des définitions empiriques qui ont été proposées pour caractériser les verres en se basant sur la façon dont ils se comportent au point de vue thermique, et les températures correspondantes pour quelques verres représentatifs. (*a*) Température de recuit ([62]): c'est la température à laquelle le rapport de la tension finale à la tension initiale devient minimum, lorsque la conduite du chauffage et du refroidissement est effectuée d'une manière prescrite; voir aussi Table 6. (*b*) Température de déformation ([62]): c'est la température la plus basse à laquelle on observe, après six heures, une déformation des faces polies d'un cube de 20 mm de côté, disposé dans du kieselguhr avec une diagonale verticale. (*c*) Température de cohésion ([69]): c'est la température la plus basse à laquelle deux pièces polies planes de 2 mm d'épaisseur et de 10 mm de diamètre s'accoleront en trente minutes. (*d*) Température de ramollissement; pour le Pyrex ([12]): c'est la température à laquelle une baguette de 23 cm de long. et de 0,6 mm de diamètre s'allonge sous son propre poids à raison de 1 mm par min, la baguette étant chauffée dans un four électrique sur une longueur de 9,5 cm. Pour le reste des verres ([69]), la constante t_o dans l'équation empirique à 3 constantes $(t_o - t)(S + S_o) = C$, exprimant la relation entre la tension, S (mesurée par biréfringence), produite par un refroidissement rapide d'un cube de 1 cm de côté de la température t. (*e*) Température d'écoulement ([63]): c'est la température à laquelle un cube de 25 mm de côté, disposé dans du kieselguhr, avec une diagonale verticale, s'écoule d'une façon telle que le coin ne peut plus être décelé dans un temps donné.

Tafel 5.—Thermische Konstanten typischer Glassorten

Gläser sind unterkühlte Flüssigkeiten und haben deshalb keinen Schmelzpunkt. Im folgenden sind einige empirische Definitionen angegeben, welche zur Charakterisierung des thermischen Verhaltens von Gläsern herangezogen werden. Auf die entsprechende Temperatur so bezogen, ist das thermische Verhalten einiger typischer Glassorten ebenfalls angegeben. (*a*) Kühltemperatur ([62]): Die Temperatur bei welcher das Verhältnis der Endspannung zur Anfangsspannung ein Minimum ist, wenn Erwärmung und Kühlung in vorgeschriebener Weise erfolgt. Siehe Tafel 6 und Fig. 22, 23 und 24. (*b*) Deformations-Temperatur ([62]): Die tiefste Temperatur bei welcher nach 6 Stunden eine Deformation der polierten Flächen eines 20 mm Würfels bemerkt wird, welcher in Kieselgur eingebettet ist (mit vertikaler Diagonale). (*c*) Kohäsions-Temperatur ([69]): Die tiefste Temperatur bei welcher zwei plan geschliffene Flächen, 2 mm dick, 10 mm Durchmesser in 30 Minuten zusammenschmelzen. (*d*) Erweichungs-Temperatur für Pyrex-Glas ([12]): Die Temperatur bei welcher ein Stab von 23 cm Länge und 0,6 mm Durchmesser, bei der Erhitzung der ersten obern 9,5 cm seiner Länge, im elektrischen Ofen, unter dem eigenen Gewicht eine minutliche Verlängerung um 1 mm erfährt. Für den Rest der Gläser ([69]) ist t_o die Konstante der empirischen Gleichung (drei Konstanten) $(t_o - t)(S + S_o) = C$, welche die Beziehung zum Druck S herstellt, der durch eine rasche Kühlung von der Temperatur t herunter in einem 1 cm Würfel erzeugt wird (Druckmessung nach der Doppelbrechung). (*e*) Fluss-Temperatur ([63]). Ist die Temperatur bei welcher ein 25 mm Würfel in Kieselgur eingebettet (diagonal, vertikal) zerfliesst, so, dass in der gegebenen Zeit die Ecken nicht mehr erkannt werden können.

Tabella 5.—Costanti termiche di vetri tipici

I vetri sono liquidi sopraraffreddati e non hanno perciò punto di fusione.

Qui sono indicate alcune delle proprietà proposte per caratterizzare i vetri dal punto di vista del loro comportamento termico, e sono riportate le temperature corrispondenti per alcuni vetri tipici. (*a*) Temperatura di (ricottura) ([62]): la temperatura alla quale è minimo il rapporto fra tensione finale e iniziale, quando riscaldamento e raffreddamento vengono eseguiti in una maniera prescritta. Vedi pure Tabella 6, e Fig. 22, 23 e 24. (*b*) Temperatura di deformazione ([62]): la temperatura più bassa alla quale, dopo sei ore, si osserva deformazione delle facce pulimentate di un cubo di 20 mm immerso nella farina fossile con una diagonale in posizione verticale. (*c*) Temperatura di adesione ([69]): la temperatura più bassa alla quale aderiscono in 30 minuti due pezzi pulimentati a superficie piana di 2 mm di spessore e 10 di diametro. (*d*) Temperatura di rammollimento. Per il Pyrex ([12]) è la temperatura alla quale una bacchetta di 23 cm di lunghezza e 0,6 mm di diametro si distende sotto il proprio peso alla velocità di 1 mm per minuto quando sia scaldata in un forno elettrico lungo i 9,5 cm superiori di lunghezza; per gli altri vetri ([69]) è la costante t_o nella equazione empirica a 3 costanti $(t_o - t)(S + S_o) = C$, esprimente la relazione tra sforzo, S (misurato dalla birifrangenza), prodotto raffreddando rapidamente un cubo di un centimetro dalla temperatura t. (*e*) Temperatura di scorrimento ([63]): la temperatura alla quale un cubo di 25 mm immerso in farina fossile con una diagonale disposta verticalmente, scorre fino a non potersi più distinguere il vertice nel tempo indicato.

Ind. No.	Annealing (a)	Deformation (b)	Cohesion (c)	Softening (d)	Flow temperatures (e)		
					30 min	2 hr	6 hr
1				815(12)			
3		570(62)	603(69)	648(69)			
12					850(63)	815(63)	755(63)
17	495(62)	605(62)	583(69)	565(69)	810(63)	795(63)	780(63)
24			555	647			
47			505	498(40)	740	725	685
57			632	640			
63			632	639	910	885	860
70			484	499			
71		590	632	642	845	805	785
80	585	645	694	681	845	830	795
87		650	694	735	870	835	820
90	565	645	686	681	840	815	800
91	410	460	486	490	730	695	680
98		585	547	595	780	730	685
100	390	430	493	491	660	645	630
107			465	473			
111			457	469			

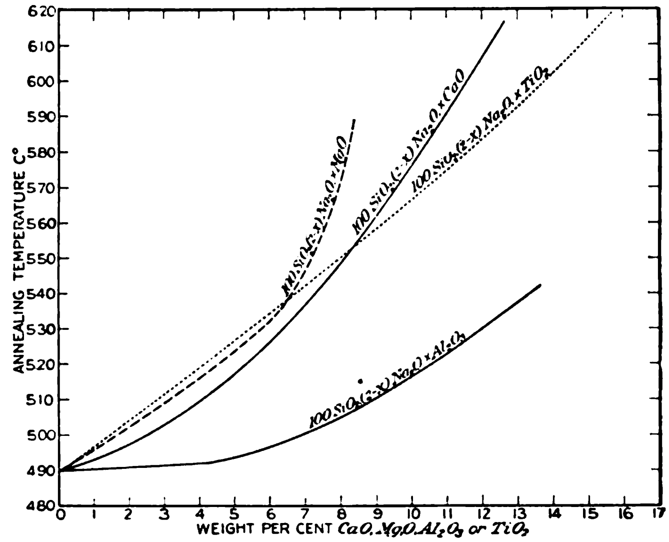

FIG. 23.—Annealing temperatures of glasses derived from $Na_2O \cdot 3SiO_2$, by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original [15, 17, 21, 55].

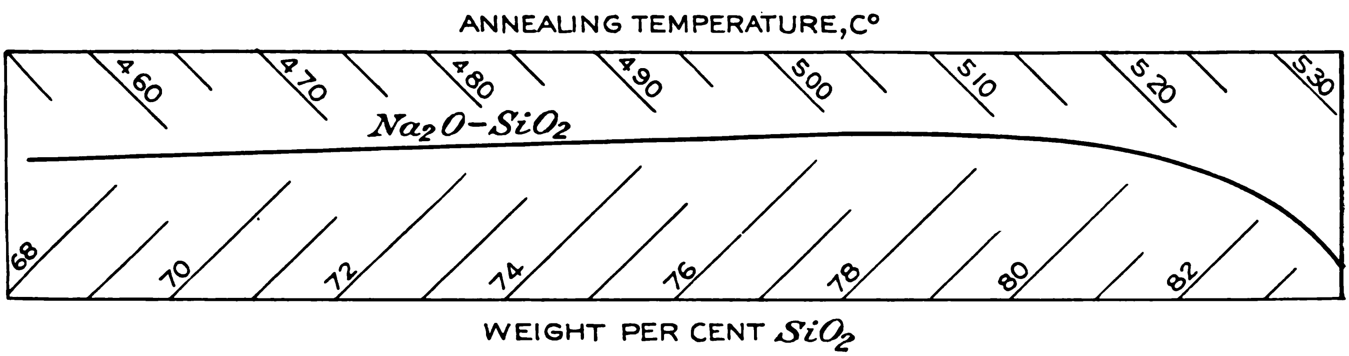

FIG. 22.—Annealing temperature of Na_2O-SiO_2 glasses [14].

Annealing Temperature

Figures 22, 23 and 24 show the relation between annealing temperature and composition of a number of experimental glasses; in these, the annealing temperature is that at which strain disappears rapidly. Table 6 gives the annealing constants of a number of optical glasses.

TABLE 6.—ANNEALING TEMPERATURES

Values of M_1 and M_2 in equation $\log_{10} A = M_1\Theta - M_2$, in which Θ = temp., °C, and M_1 and M_2 are experimental constants, from which may be calculated the annealing constant A. The annealing temperature is defined as that temperature at which the strain will decrease from 50 to 2.5$\mu\mu$ in 2 min, calculated from the formula $At = 1/\Delta n - 1/\Delta n_o$ in which t = time in min, Δn = birefringence in $\mu\mu$.

Ind. No.	Type	M_1	M_2	Annealing temp., °C
19	516/620	0.030	18.68	599
36	523/590	0.029	17.35	573
65	573/420	0.033	15.92	461
67	574/570	0.032	20.10	606
82	606/440	0.028	16.28	556
83	608/570	0.038	24.95	638
95	616/370	0.038	18.34	464
103	655/330	0.037	17.51	454
110	756/270	0.033	15.03	434

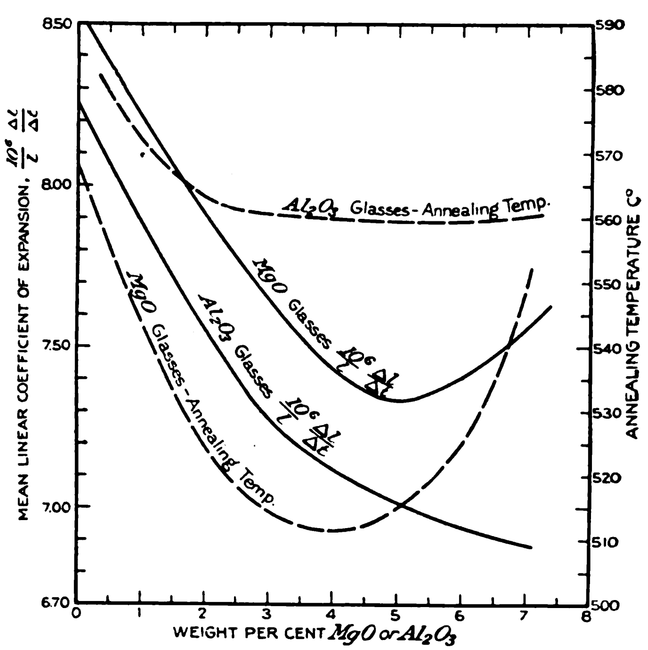

FIG. 24.—Annealing temperatures and thermal expansions of glasses derived from $1.2Na_2O \cdot 0.8CaO \cdot 6SiO_2$ by substitution of CaO by MgO; and from $1.1Na_2O \cdot 0.9CaO \cdot 6SiO_2$ by substitution of CaO by Al_2O_3 [21, 25].

Coefficient of Expansion

The linear coefficient of expansion, $\alpha = 10^6 \Delta l / l \Delta t$, of multicomponent commercial and experimental glasses is given in Tables 2 and 7 and for a systematic series of experimental glasses in Figs. 24–28.

TABLE 7.—COEFFICIENT OF THERMAL EXPANSION
($V.$ *also* Table 2) $l = l_o\,(1 + 10^{-6}\alpha t)$

Ind. No.	α	Range, °C	Lit.	Ind. No.	α	Range, °C	Lit.
13	9.12	18–97	(34)	71	7.02		(69)
17	7.79		(69)	74	8.8	22–451	(48)
23	9.20	37 (mean)	(34)		34.7	494–512	(48)
	10.04	93 (mean)	(34)	75	8.23		(69)
	10.61	151 (mean)	(34)	78	7.0	23–420	(48)
	11.11	212 (mean)	(34)		2.92	495–511	(48)
24	9.00		(69)	80	5.87		(69)
26	10.2	22–426	(48)	87	6.48		(69)
	55.5	502–522	(48)	91	7.88	11–99	(51)
28	10.4	24–422	(48)	98	8.76		(69)
	54.8	494–507	(48)	102	8.75		(69)
30	9.00	22–498	(48)	107	8.33		(69)
	39.3	539–562	(48)	109	8.03	20–94	(34)
33	9.03	16–94	(34)	111	8.18		(69)
45	5.23	7–92	(34)	114	9.34	18–99	(51)
47	8.14		(69)	134	6.74	14–94	(34)
51	8.8	22–494	(48)	136	5.60	0–100	(34)
	33.1	519–550	(48)	138	5.37	0–100	(34)
54	7.74		(69)	141	9.30	18–93	(34)
61	9.00	10–93	(34)	145	8.71	21–100	(51)
64	9.0	23–499	(48)	122	*	−253 to	(2)
	64.9	569–610	(48)			+100	

* $l = l_o\{1 + 10^{6}\,[716.8\,(T/100) + 48.33\,(T/100)^2 + 9.02\,(T/100)^3 + 10.9\,(T/100)^4]\}$.

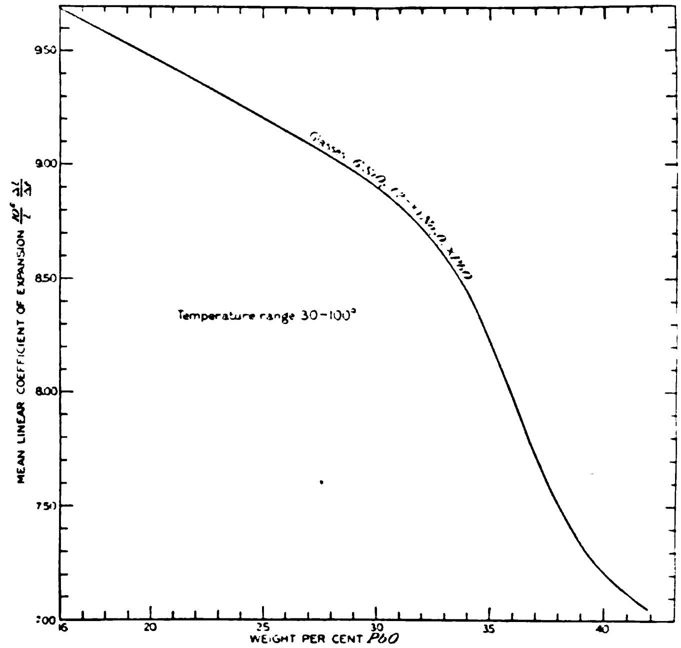

FIG. 27.—Thermal expansion of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of PbO for Na_2O (42).

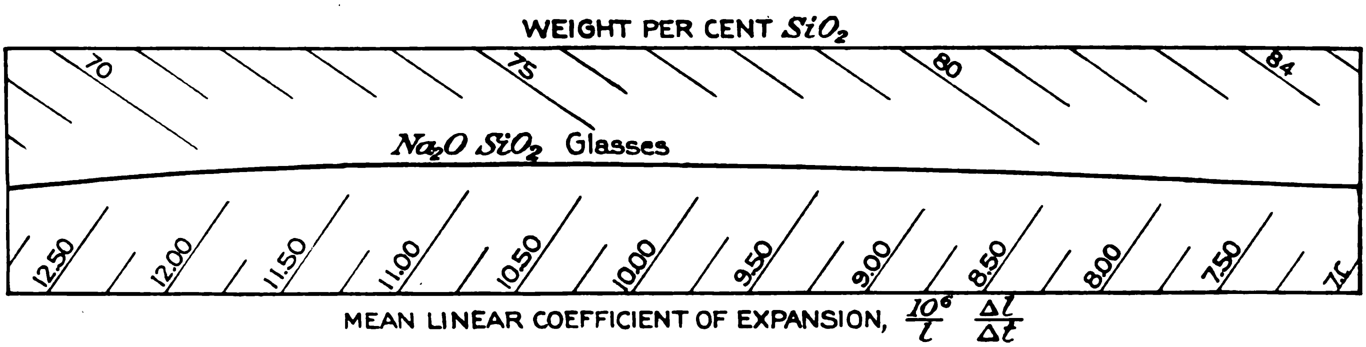

FIG. 25.—Thermal expansion of Na_2O-SiO_2 glasses (22).

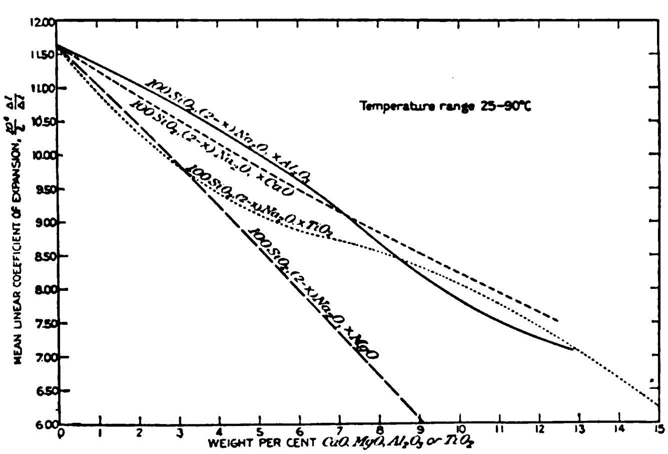

FIG. 26.—Thermal expansion of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original (16, 18, 23, 55).

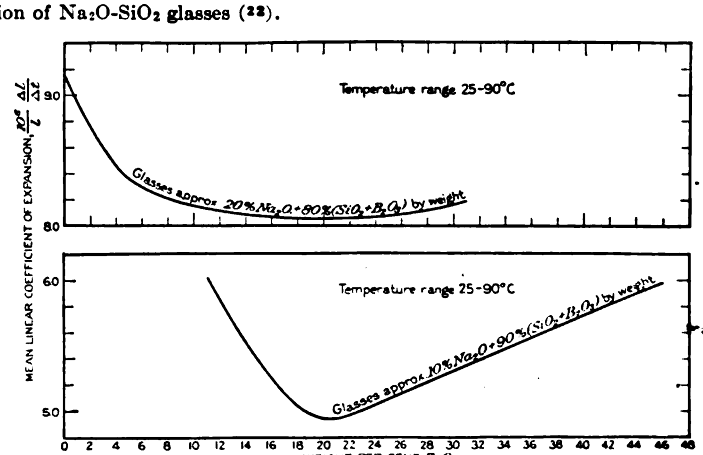

FIG. 28.—Thermal expansion of Na_2O-B_2O_3-SiO_2 glasses (28).

SPECIFIC HEAT

The specific heats of commercial and experimental glasses are given in Table 2; Table 8 gives the specific heats of mineral glasses.

TABLE 8.—MEAN SPECIFIC HEATS OF SILICATE GLASSES

g cal_{15}/g per °C; *v. also* Table 2

These determinations are the most accurate in the literature and the compositions are well established ([64]).

Glass	0–100°	0–300°	0–500°	0–700°	0–900°	0–1100°
Anorthite, An $CaO \cdot Al_2O_3 \cdot 2SiO_2$..	0.1881	0.2152	0.2306	0.2406		
Andesine, Ab_1 An_1..	0.1932	0.2211		0.2484	0.2615	
Albite, Ab $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$.	0.1977	0.2238	0.2410		0.2640	
Microcline $K_2O \cdot Al_2O_3 \cdot 6SiO_2$..	0.1919	0.2163	0.2321	0.2431	0.2515	0.2598
Wollastonite $CaO \cdot SiO_2$.........	0.1852	0.2078	0.2208	0.2355		
Diopside $CaO \cdot MgO \cdot 2SiO_2$..	0.1938	0.2189	0.2333	0.2439		
Magnesium metasilicate $MgO \cdot SiO_2$........	0.2040	0.2302	0.2474	0.2598		

Thermal Conductivity

TABLE 9.—THERMAL CONDUCTIVITY ([29])

Ind. No.	Glass type	g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ −190°	−78°	0°	100°
3	496/644	1.181	2.532	2.796	3.243
17	516/640	1.195		2.825	
91	613/369	0.865		1.900	
102	649/338	0.851		1.867	
109	754/275	0.807		1.698	1.812
141	516/692	0.877		1.796	2.007

ELECTRICAL PROPERTIES

TABLE 10.—MAGNETIC SUSCEPTIBILITY ([35])

Magnetic susceptibility, κ, in units of 10^6 cgs, as function of magnetic field-strength, *H*, in gausses

Ind. No.	κ H = 1350	κ H = 1800	κ H = 2200	Ind. No.	κ H = 1350	κ H = 1800	κ H = 2200
4	−0.90	−0.90	−0.90	52	−0.93	−0.93	−0.93
11	−0.85	−0.865	−0.885	72	−0.91	−0.92	−0.93
12	−0.93	−0.93	−0.93	75		−0.38	−0.395
35	−0.59	−0.60	−0.607	87	−0.95	−0.95	−0.95
45	−0.78	−0.78	−0.78	105	−1.01	−1.01	−1.01

TABLE 11.—DIELECTRIC PROPERTIES

The factors which measure the value of a dielectric are: (*a*) dielectric constant, ε; (*b*) dielectric strength, measured by the sparking voltage, and varying with the thickness of material tested; and, (*c*) the energy taken up by the dielectric, measured either by the phase angle, PA, between displacement current and charging current, or by the power factor, *PF*, the cosine of the phase angle.

(*a*) Dielectric constant, ε

Ind. No.	Glass type	ε	Lit.	Ind. No.	Glass type	ε	Lit.
1	Pyrex	4.83*	([12])	81	604/438	7.71	([54.1])
(Near 2)	464/657	5.81	([54.1])	84	610/574	8.20	([54.1])
17	516/640	6.2	([13])	90	614/564	7.6	([13])
31	520/520	6.92	([54.1])	91	613/369	7.47	([54.1])
37	523/513	4.8	([13])	96	620/362	6.8	([13])
41	537/512	6.7	([13])	107	717/295	8.5	([13])
60	569/426	6.5	([13])	(Near 113)	917/	16.2	([54.1])

* (50 000 cycles.)

(*b*) Dielectric strength. Unit: 10^3 volts cm^{-1}

Ind. No.	Glass type	Thickness tested, mm	*D. S.*	Lit.
1	Pyrex	6.35	134	([12])
15	513/573	0.41	429	([13])
		1.42	220	([13])
		2.28	179	([13])
70	576/408	0.41	1000	([13])
136	519/609	1.49	240	([13])
		1.60	252	([13])

(*c*) Energy adsorption in dielectric

Ind. No.	Type	*PF*, %	Ind. No.	Type	PA min
1	Pyrex lab.	0.52	58	570/560	2.81
1a	Pyrex radio	0.18	63	573/575	2.68
		PA min	70	577/414	1.82
(Near 2)	464/656	6.14	84	611/572	1.90
3	501/659	11.46	91	613/369	1.54
17	516/640	6.80	96	620/363	1.39
22	519/604	7.85	102	649/338	1.40
33	526/513	22.6	104	657/363	1.48
38	529/518	2.94	111	778/265	2.60

TABLE 12.—ELECTRICAL RESISTIVITY AND CONDUCTIVITY

(*a*) Resistivity

Ind. No. 1, Pyrex: Surface resistivity ([12]): 10^{14} ohm at 34% humidity, 5×10^9 ohm at 84% humidity. Volume resistivity ([12]): 10^{14} ohm-cm.

(*b*) Conductivity, κ. Unit: 10^{12} ohm^{-1} cm^{-1}

Ind. No.	100°	125°	150°	175°	200°	Lit.
12	0.012	0.0703	0.334	1.59	6.90	([6])
23	0.0132	0.0672	0.425	2.32		([6])
44	0.00542	0.0418	0.221	1.57	7.69	([6])
52	0.0190	0.0416	0.0968	0.5076	2.38	([6])
70	0.0025	0.015	0.0684	0.668	2.544	([6])
85	0.00256	0.0134	0.0406	0.106	0.374	([6])
96	0.00233	0.00994	0.039	0.116	0.393	([6])
131	132	462	2 650	8 700	26 300	([6])
132	103	456	1 692	5 854	17 800	([6])
133	542	302	1 400	4 740		([6])

Unit: 10^7 ohm^{-1} cm^{-1}

Ind. No.	t°	κ	t°	κ	t°	κ	t°	κ	
6	250	129	402	4008	502	13 000	602	50 000	([5])
8	250	6.77	400	415.8	489	2 100			([5])
122	250	2.5	409	90.8	500	345	600	1 178	([5])

OPTICAL PROPERTIES

The relations between composition and optical properties in several systematic series are shown in Figs. 29–36. The properties of typical optical glasses are shown in Table 13, which, together with the compositions, was furnished by Chance Bros. and Co., Ltd. Table 14 gives the index for the infra-red and ultra-violet; Table 15, the effect of temperature on index; Table 16, the effect of pressure and strain; and Table 17, the absorption of light by various glasses.

TABLE 13.—DISPERSIONS OF TYPICAL OPTICAL GLASSES (9)

Ind. No.	n_D	Mean dispersion $n_F - n_C$	$\nu = \left(\frac{n_D - 1}{n_F - n_C}\right)$	Partial dispersions and relative partial dispersions D-C	F-D	G'-F	Sp. gr.
2	1.4785	0.00682	70.2	0.00202	0.00480	0.00363	2.47
				.296	.704	.532	
5	1.4980	.00763	65.3	.00227	.00536	.00425	2.40
				.298	.702	.557	
9	1.5087	.00793	64.1	.00237	.00556	.00445	2.46
				.299	.701	.561	
18	1.5160	.00809	63.8	.00242	.00567	.00454	2.54
				.299	.701	.561	
10	1.5100	.00821	62.1	.00246	.00575	.00462	2.50
				.299	.701	.562	
79	1.5881	.00962	61.1	.00287	.00675	.00541	3.31
				.298	.702	.563	
20	1.5155	.00848	60.8	.00250	.00598	.00482	2.48
				.295	.705	.568	
27	1.5175	.00856	60.5	.00254	.00602	.00484	2.49
				.297	.703	.565	
29	1.5186	.00860	60.3	.00254	.00606	.00489	2.49
				.295	.705	.569	
89	1.6130	.01025	59.8	.00302	.00723	.00582	3.58
				.294	.706	.568	
43	1.5407	.00910	59.4	.00268	.00642	.00517	2.90
				.295	.705	.568	
86	1.6118	.01037	59.0	.00305	.00732	.00590	3.56
				.294	.706	.569	
16	1.5149	.00890	57.9	.00265	.00625	.00506	2.62
				.298	.702	.569	
66	1.5744	.00995	57.7	.00292	.00703	.00567	3.23
				.293	.707	.570	
90	1.6134	.01090	56.3	.00319	.00771	.00626	3.58
				.292	.708	.575	
94	1.6150	.01097	56.1	.00323	.00776	.00630	3.58
				.292	.708	.575	
77	1.5837	.01041	56.1	.00304	.00737	.00596	3.29
				.292	.708	.573	
58	1.5661	.01029	55.0	.00301	.00728	.00591	3.14
				.293	.707	.574	
37	1.5237	.01003	52.2	.00295	.00708	.00577	2.67
				.294	.706	.575	
50	1.5515	.01067	51.7	.00310	.00757	.00619	2.99
				.291	.709	.581	
40	1.5290	.01026	51.6	.00300	.00726	.00593	2.56
				.292	.708	.578	
49	1.5523	.01075	51.4	.00313	.00762	.00624	3.06
				.291	.709	.581	
76	1.5833	.01251	46.6	.00362	.00889	.00738	3.30
				.289	.711	.590	
53	1.5534	.01201	46.1	.00347	.00854	.00711	2.96
				.289	.711	.592	
46	1.5472	.01196	45.8	.00348	.00848	.00707	2.93
				.291	.709	.591	
48	1.5491	.01206	45.5	.00348	.00858	.00714	2.95
				.289	.711	.592	
56	1.5677	.01291	44.0	.00371	.00920	.00763	3.08
				.288	.712	.591	
55	1.5632	.01312	42.9	.00375	.00937	.00781	3.07
				.286	.714	.595	
69	1.5746	.01388	41.4	.00396	.00992	.00830	3.18
				.285	.715	.598	
72	1.5787	.01420	40.8	.00406	.01014	.00851	3.26
				.286	.714	.599	
93	1.6125	.01655	37.0	.00471	.00184	.01003	3.54
				.285	.715	.606	
92	1.6134	.01662	36.9	.00473	.01189	.01008	3.55
				.285	.715	.606	
97	1.6214	.01722	36.1	.00491	.01231	.01047	3.63
				.285	.715	.608	
104	1.6683	.01876	35.6	.00533	.01343	.01147	3.98
				.284	.716	.611	
101	1.6469	.01917	33.7	.00541	.01376	.01170	3.87
				.282	.718	.610	
106	1.7167	.02430	29.5	.00686	.01744	.01511	4.47
				.282	.718	.622	

The order is that of decreasing ν.

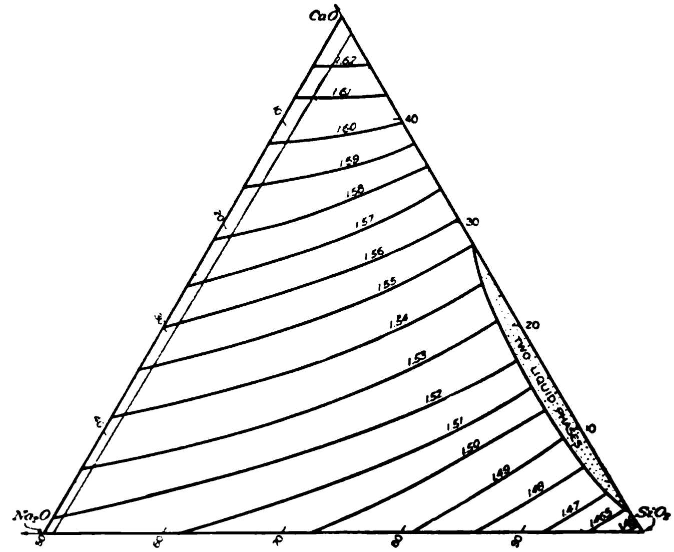

FIG. 29.—Refractive index of Na_2O-CaO-SiO_2 glasses (41).

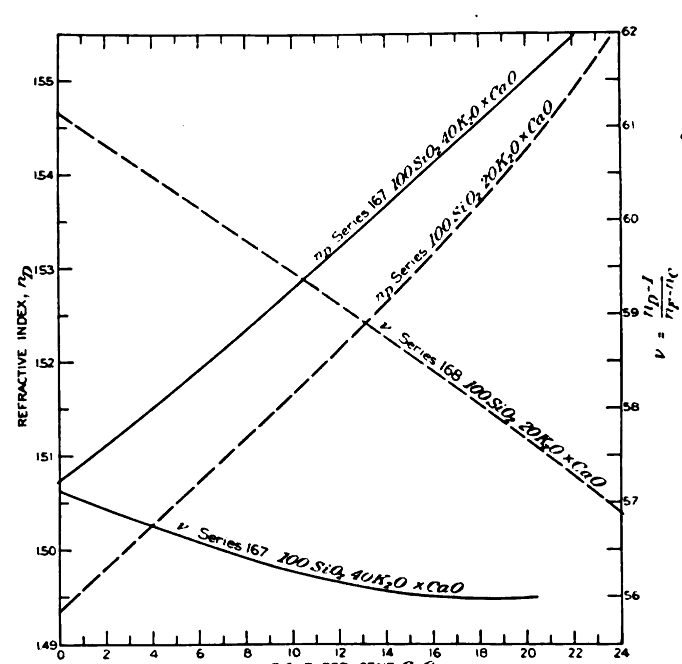

FIG. 30.—Refractive index and γ-value of K_2O-CaO-SiO_2 glasses of the approximate composition shown (45).

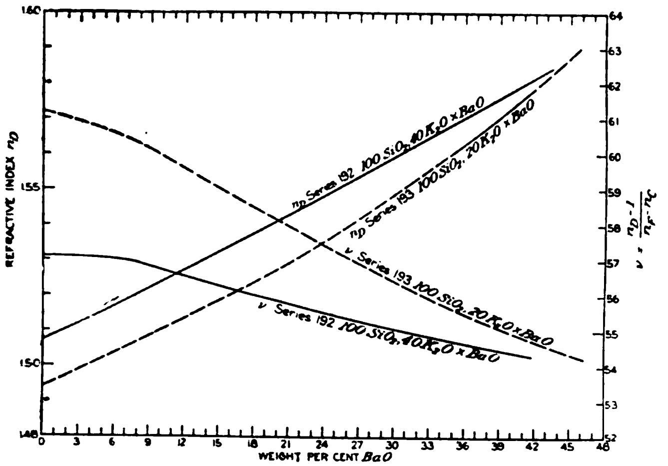

FIG. 31.—Refractive index and γ-value of Na_2O-BaO-SiO_2 glasses of the approximate composition shown (46).

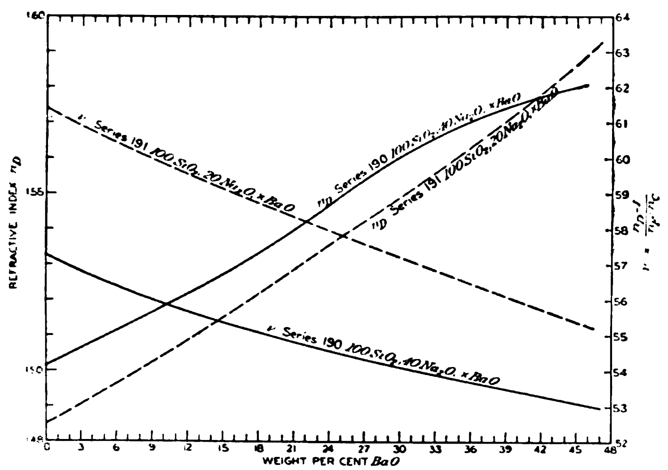

FIG. 32.—Refractive index and γ-value of K_2O-BaO-SiO_2 glasses of the approximate composition shown (46).

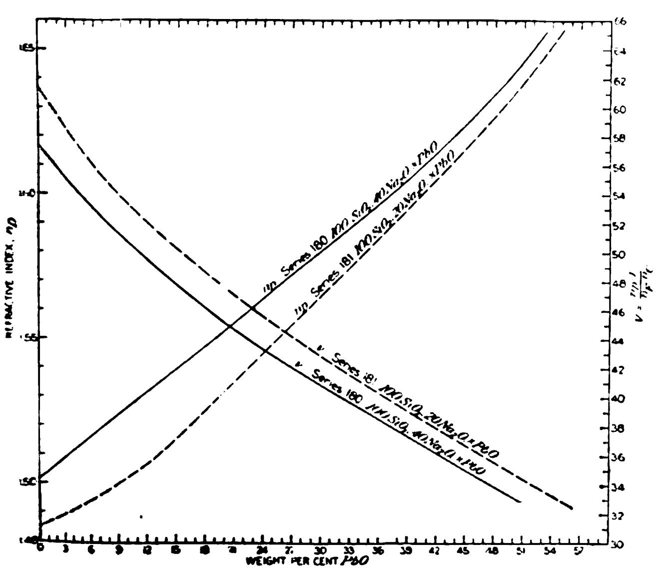

FIG. 33.—Refractive index and γ-value of Na_2O-PbO-SiO_2 glasses of the approximate composition shown (47).

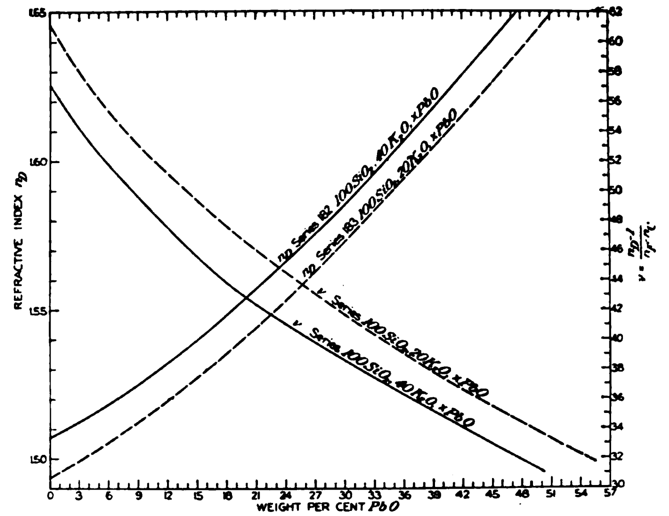

FIG. 34.—Refractive index and γ-value of K_2O-PbO-SiO_2 glasses of the approximate composition shown (47).

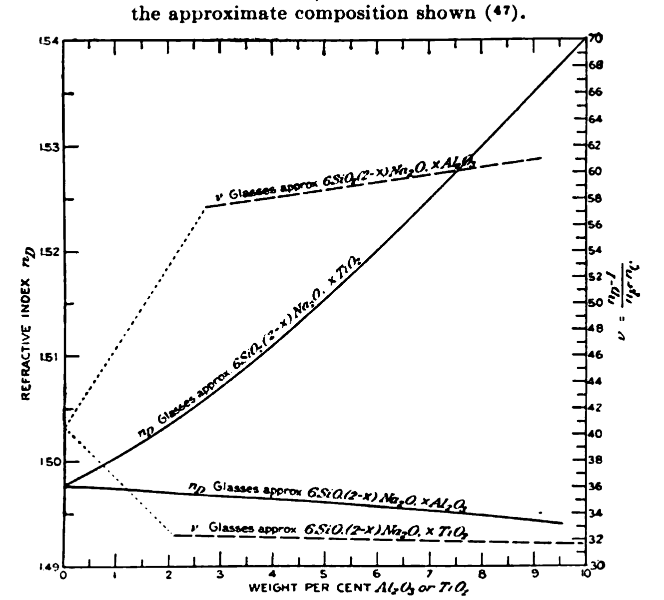

FIG. 35.—Refractive index and γ-value of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original (10, 55).

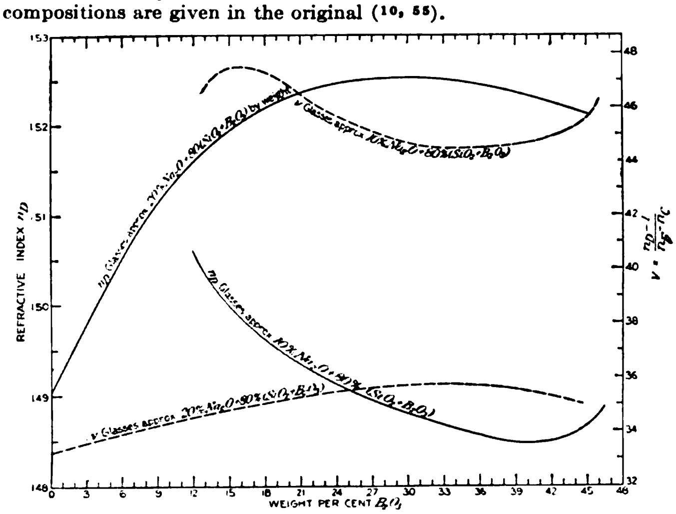

FIG. 36.—Refractive index and γ-value of Na_2O-B_2O_3-SiO_2 glasses. Exact compositions are given in the original (28)

TABLE 14.—REFRACTIVE INDICES FOR VARIOUS WAVE LENGTHS

Source	Wave length $\mu\mu$	Index number (from Table 1) and Lit.												
		134(60)	135(53)	12(60)	24(60)	25(60)	31(53)	32(55)	38(60)	39(60)	42(60)	54(60)	144(53)	57(60)
	2200					1.4943								
	2000		1.4845			1.4967	1.4973						1.5390	
	1800		1.4884			1.4988	1.4999						1.5424	
	1600		1.4919			1.5008	1.5024						1.5452	
	1400		1.4950			1.5027	1.5048						1.5476	
	1200		1.4979			1.5048	1.5069						1.5497	
	1000		1.5009			1.5071	1.5096						1.5522	
	800		1.5044			1.5103	1.5131						1.5555	
K_α(A′)	768		1.50426			1.51143	1.51368	1.51410					1.55651	
H_α(C)	656.3	1.50486	1.50742	1.50883	1.51436	1.51446	1.51712	1.51742	1.51932	1.52441	1.53755	1.55771	1.55957	1.56014
Cd_1	643.9	1.50525		1.50917	1.51482				1.51979	1.52490	1.53797	1.55821	1.55821	1.56068
Na(D)	589.0	1.50734	1.51007	1.51124	1.51693	1.51698	1.52002	1.52046	1.52231	1.52704	1.54025	1.56075	1.56207	1.56343
Cd_2	537.9	1.50976		1.51362	1.51957				1.52536	1.52961	1.54297	1.56375		1.56671
Tl_α	534.9		1.51287			1.51971	1.52327	1.52363					1.56476	
Cd_3	533.8	1.51004		1.51386	1.51982				1.52568	1.52989	1.54321	1.56407		1.56689
Cd_4	508.6	1.51154	1.51447	1.51534	1.52143	1.52132	1.52525	1.52567	1.52754	1.53146	1.54489	1.56596	1.56643	1.56914
H_β(F)	486.1		1.51610	1.51690		1.52299	1.52715	1.52752	1.52954	1.53303			1.56794	1.57148
Cd_5	479.9	1.51362	1.51662	1.51732	1.52361	1.52354	1.52782	1.52824	1.53007	1.53362	1.54714	1.56844	1.56847	1.57193
Cd_6	467.8	1.51461	1.51769	1.51828	1.52466	1.52451	1.52903	1.52946	1.53129	1.53464	1.54825	1.56968	1.56949	1.57333
Cd_7	441.6	1.51704		1.52066	1.52725				1.53436	1.53721	1.55093	1.57268		1.57667
H_γ(G′)	434.0	1.51775	1.52092	1.52136		1.52778	1.53312	1.53341	1.53521	1.53790			1.57273	1.57764
Cd_8	398.8	1.52210		1.52546	1.53261				1.54075	1.54245	1.55646	1.57896		1.58375
Cd_9	361.2	1.52852	1.53195	1.53156	1.53943	1.53897	1.54664	1.54726	1.54897	1.54911	1.56354	1.58704	1.58330	1.59300
Cd	353.6	1.53010			1.54111					1.55071	1.56525			1.59526
Cd_{10}	346.7	1.53157	1.53509	1.53445	1.54272	1.54215	1.55068	1.55132	1.55300	1.55225	1.56689	1.59093	1.58632	1.59754
Cd_{11}	340.4	1.53307	1.53660	1.53586	1.54432	1.54369	1.55262	1.55330	1.55504	1.55379	1.56852	1.59279	1.58776	1.59978
Cd	334.5	1.53490							1.55746	1.55564	1.57046	1.59452		1.60248
Cd_{12}	328.4	1.53721		1.53982	1.54879				1.56043	1.55804	1.57296	1.59796		1.60593
Cd	326.4	1.53811							1.56157					1.60748
Cd	326.1		1.54046			1.54755	1.55770	1.55838					1.59138	
Cd	323.6	1.53896								1.56004		1.60033		1.60900
Cd	322.1	1.53932		1.54168					1.56311	1.56086	1.57511	1.60081		1.61015
Cd	321.0			1.54204										
Cd	320.2	1.53982		1.54238	1.55089					1.56175	1.57593			1.61189
Cd	318.5	1.54079			1.55175				1.56518	1.56193	1.57830	1.60263		
Cd	315.7			1.54475	1.55414				1.56675			1.60475		
Cd_{13}	313.3		1.54444	1.54536	1.55450	1.55159	1.56307	1.56381		1.56343	1.57870			
Cd_{14}	308.1		1.54625	1.54839	1.55875	1.55343	1.56558	1.56632		1.56661	1.58293			
Cd	306.5								1.56714	1.56714				
Cd	298.0		1.55005			1.55723	1.57093	1.57176						
Cd	288.0		1.55437			1.56161								
Cd	283.7		1.55648			1.56372								
Cd	276.3		1.56027			1.56759								
	2400			1.5440							1.6131			1.8286
	2200			1.5463							1.6150		1.7082	1.8310
	2000		1.5515	1.5487							1.6171		1.7104	1.8316
	1800		1.5541	1.5512							1.6193		1.7127	1.8364
	1600		1.5565	1.5535							1.6217		1.7151	1.8396
	1400		1.5588	1.5559							1.6246		1.7180	1.8433
	1200		1.5611	1.5585							1.6277		1.7215	1.8481
	1000		1.5637	1.5615							1.6315		1.7264	1.8541
	800		1.5673	1.5659							1.6373		1.7339	1.8650
K_α(A′)	768	1.56731	1.56782	1.56669		1.57508		1.60277			1.63820		1.73530	1.86702
H_α(C)	656.3	1.57073	1.57120	1.57119	1.57568	1.57934	1.58848	1.60644	1.61574	1.62285	1.64440	1.65326	1.74368	1.87893
Cd_1	643.9				1.57619		1.58896		1.61656	1.62356		1.65435		
Na(D)	589.0	1.57363	1.57422	1.57524	1.57893	1.58282	1.59144	1.60956	1.62073	1.62750	1.64985	1.65762	1.75130	1.88995
Cd_2	537.9				1.58211		1.59433		1.62578	1.63226		1.66146		
Tl_α	534.9	1.57687	1.57746	1.57973		1.58689		1.61292			1.65601		1.75995	1.90262
Cd_3	533.8				1.58244		1.59463		1.62630	1.63274		1.66185		
Cd_4	508.6	1.57883	1.57938	1.58247	1.58444	1.58941	1.59644	1.61504	1.62952	1.63577	1.65979	1.66423	1.76539	
H_β(F)	486.1	1.58079	1.58126	1.58515	1.58646	1.59178	1.59825	1.61706			1.66367	1.66670	1.77091	1.91890

Source	Wave length $\mu\mu$	Index number (from Table 1) and Lit. 68(55)	68(53)	70(54)	71(60)	75(55)	80(60)	84(55)	96(60)	98(60)	102(53)	139(60)	108(53)	112(53)
Cd_5	479.9	1.58132	1.58188	1.58594	1.58715	1.59257	1.59878	1.61770	1.63396	1.63992	1.66482	1.66742	1.77256	
Cd_6	467.8	1.58253	1.58306	1.58772	1.58848	1.59419	1.59996	1.61891	1.63615	1.64196	1.63725	1.66904	1.77609	
Cd_7	441.6				1.59174		1.60285		1.64162	1.64704		1.67292		
$H_\gamma(G^1)$	434.0	1.58651	1.58710	1.59355	1.59268	1.59920	1.60367	1.62320	1.64319		1.67561	1.67436	1.78800	1.94493
Cd_8	398.8				1.59852		1.60870		1.65333	1.65792		1.68104		
Cd_9	361.2	1.59951	1.60022	1.61388	1.60726	1.61691	1.61622	1.63683	1.66933	1.67269	1.70536	1.69146	1.83263	
Cd	353.6				1.60937		1.61800		1.67346			1.69400		
Cd_{10}	346.7	1.60326	1.60399	1.62008	1.61148	1.62228	1.61978	1.64077	1.67753	1.68018	1.71485	1.69648	1.84731	
Cd_{11}	340.4	1.60510	1.60583	1.62320	1.61356	1.62492	1.62148	1.64271	1.68160	1.68390	1.71968	1.69892	1.85487	
Cd	334.5				1.61559		1.62356		1.68685	1.68838		1.70135		
Cd_{12}	328.4				1.61922		1.62622		1.69265	1.69454		1.70408		
Cd	326.4				1.62069				1.69356			1.70562		
Cd	326.1	1.60973	1.61045	1.63134		1.63166		1.64754			1.73245			
Cd	323.6				1.62159									
Cd	322.1													
Cd	321.0													
Cd	320.2				1.62256									
Cd	318.5				1.62311									
Cd	315.7				1.62462									
Cd_{13}	313.3	1.61446	1.61525	1.64024	1.62678	1.63908		1.65254						
Cd_{14}	308.1	1.61664	1.61744	1.64453		1.64258								
Cd	306.5													
Cd	298.0	1.62122	1.62213	1.65397										
Cd	288.0	1.62642	1.62742											
Cd	283.7	1.62893	1.62997											
Cd	276.3													

Index number 108(54) Wave length μ	n	Wave length $\mu\mu$	n
4.12	1.6688	1.216	1.7208
3.83	1.6758	936	1.7276
3.56	1.6821	769.93	1.735000
3.24	1.6885	656.33	1.743488
2.98	1.6934	589.32	1.751094
2.71	1.6980	534.96	1.759751
2.40	1.7029	486.16	1.770658
2.02	1.7086	434.09	1.787782
1.625	1.7144	404.44	1.801758

Table 15.—Effect of Change in Temperature on the Absolute Refractive Index of Glass

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5\Delta n/\Delta t$, $\Delta t = \pm 50°$ C	D	F	G′	Lit.
14	513/637	52.8	+0.119	+0.137	+0.178	+0.213	(51)
23	517/602	59.3	−0.129	−0.105	−0.060	−0.010	(51)
45	545/503	59.2	+0.267	+0.299	+0.356	+0.410	(51)
60	571/430	58.0	+0.226	+0.250	+0.307	+0.360	(52)
		149.6	+0.324	+0.362	+0.456	+0.548	
		251.5	+0.509	+0.568	+0.666	+0.768	
		351.5	+0.577	+0.639	+0.751	+0.870	
		436.5	−1.861	−1.720	−1.504	−1.329	
61	572/504	56.5	+0.014	+0.045	+0.107	+0.150	(52)
		157.1	0.094	0.111	0.179	0.246	
		261.5	0.144	0.167	0.249	0.355	
		357.0	0.217	0.249	0.350	0.461	
63	573/576	61.2	0.024	0.035	0.092	0.099	(52)
		154.0	0.096	0.113	0.152	0.186	
		257.0	0.156	0.174	0.223	0.258	
		358.0	0.221	0.247	0.297	0.340	
84	610/574	55.9	0.394	0.410	0.504	0.528	(52)
		148.0	0.419	0.444	0.543	0.517	
		251.0	0.455	0.489	0.603	0.629	
		356.5	0.509	0.555	0.648	0.682	

Table 15.—Effect of Change in Temperature on the Absolute Refractive Index of Glass.—(*Continued*)

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5\Delta n/\Delta t$, $\Delta t = \pm 50°$ C	D	F	G′	Lit.
91	613/369	55.1	0.244	0.281	0.389	0.503	(51)
109	755/275	57.7	0.703	0.778	1.058	1.294	(52)
		126.0	0.916	1.051	1.302	1.668	
		176.5	0.960	1.092	1.430	1.714	
		231.0	1.127	1.237	1.632	1.993	
		280.5	1.277	1.396	1.790	2.140	
		325.0	1.382	1.544	1.960	2.405	
		379.0	1.758	1.904	2.263	2.893	
112	890/226	60.5	1.119	1.278	1.752	2.161	(52)
		125.5	1.275	1.442	1.959	2.477	
		177.5	1.379	1.594	2.098	2.617	
		250.5	1.577	1.783	2.396	2.992	
		330.0	1.808	2.027	2.753		
114	963/197	62.6	1.218	1.472	2.110	2.800	(52)
		156.2	1.579	1.809	2.536		
		233.0	1.928	2.251	3.212		
		281.0	1.591	1.911	2.918		
134	507/604	60	−0.066	−0.074	−0.033	−0.003	(51)
141	516/703	58.1	−0.202	−0.190	−0.168	−0.142	(51)
145	562/665	60.3	−0.314	−0.305	−0.246	−0.237	(51)

Table 16.—Effect of Pressure on Optical Properties

The birefringence produced by a thrust F is measured in terms of the difference in index for white light of the two rays: $n_y - n_z = BF$, in which $B = \frac{n}{2R}\left(\frac{q}{v} - \frac{p}{v}\right)$, in which R = rigidity, $\frac{q}{v}$ and $\frac{p}{v}$, optical coefficients. The effect of uniform pressure, P', can be calculated from the equation $\frac{n_x - n}{n} = \frac{P'}{E}(1 - 2\sigma)\left(\frac{2p}{v} + \frac{q}{v}\right)$, in which E and σ are Young's modulus and Poisson's ratio. Unit of $F = 10^{-13}$ barye.

Ind. No.	Type	F	p/v	q/v	Lit.
19	516/620	−2.79			(1)
36	523/590	−2.52			(1)
41	537/512	−2.66			(30)
45	545/503	−3.70	0.289	0.182	(50)
60	571/430	−2.87	0.306	0.213	(50)
65	573/420	−3.13			(1)
67	574/570	−2.75			(1)
82	606/440	−3.03			(1)
83	608/570	−2.10			(1)
95	616/370	−3.06			(1)
96	621/361	−2.77			(30)
100	645/341	−2.56	0.335	0.264	(50)
103	655/330	−2.61			(1)
105	680/317	−2.17			(30)
107	717/295	−1.70			(30)
108	751/276	−1.30	0.354	0.319	(50)
110	756/270	−1.19			(1)
114	963/197	+1.88	0.427	0.466	(50)
134	507/614	−4.23	0.274	0.166	(50)

Table 17a.—Transmission Factor

$A = I/I_0$ (*v.* vol. I, p. 34); ultraviolet region; wave length, λ, in $\mu\mu$; In. = Index number of glass

λ \ In.	12	23	39	52	71	81	84	98	99	105
Glass thickness, 1 mm (36)										
384					0.995	0.986	0.989	0.983	0.985	0.947
361	0.995	0.995	0.994		.984	.962	.958	.952	.959	.83
347	.988	.991	.983	0.988	.959	.925	.88	.92	.89	.64
330	.957	.974	.938	.959	.89	.75	.76	.71	.74	.33
309	.78	.70		.69	.65					
Glass thickness, 10 mm (36)										
434					0.969					
425	0.993	0.982	0.970	0.978	.961	0.963	0.965	0.952	0.961	0.905
415	.982		.968	.973	.965					
406			.964		.974					
396	.986	.981	.980	.987	.971	.931	.941	.917	.944	.76
384	.972	.975	.955	.968	.948	.865	.894	.84	.86	.58
361	.950	[illegible]	.942	.952	.849	.68	.65	.61	.66	.16
347	.88	.91	.85	.88	.66	.46	.28	.41	.30	.01
330	.65	.77	.53	.66	.32	.06	.07	.03	.05	0
309	.08	.03	0	.02	.01	0	0	0	0	0
Glass thickness, 100 mm (36)										
480	0.95	0.97	0.93	0.96		0.94		0.94	0.94	0.89
468	0.94	0.93	0.91	0.94		0.86		0.87	0.95	0.83
448	0.93	0.92	0.81	0.89		0.79		0.79	0.83	0.63
434					0.73					
425	0.94	0.83	0.74	0.80	0.67	0.68	0.70	0.61	0.67	0.67
415	0.84		0.72	0.76	0.70					
406			0.70		0.77					
396	0.87	0.82	0.82	0.88	0.74	0.49	0.54	0.42	0.56	0.06
384	0.75	0.78	0.63	0.72	0.59	0.23	0.33	0.18	0.22	0
361	0.60	0.60	0.55	0.61	0.19	0.02	0.13	0.01	0.01	
347	0.92	0.38	0.19	0.29	0.02	0	0	0	0	
330	0.01	0.07	0	0.02	0					

Ind. No. 1, pyrex, 1 mm thick (12)

λ	396	384	361	347	330	309	280
A	1.00	0.97	0.93	0.85	0.70	0.50	0.05

Table 17b.—Factor (1-A)

Absorption for 1 cm path for the visible spectrum (49)

Ind. No.	Type	Wave length in $\mu\mu$: 357	388	415	442	500	640
12	510/640	4.7	2.5	1.2		0.7	0.5
23	518/602	3.4	2.5	1.8	1.4	0.5	0.3
38	523/513	49	30	12	3.6	0.7	0.7
59	568/530	9	6	2.7		1.6	
75	583/464	18	8.6	2.5	2.1	0.9	0.5
84	611/572	35	9.8	5.2	3.4	2.5	1.6
96	620/362	28	9.6	4.1		0.0	0.0
100	649/338	41	28	6.9		0.9	0.5

Table 17c.—Absorption Constant, k, ($I = I_0e^{-kd}$) for the Infra-red Spectral Range (53)

Ind. No.	Wave length in μ: 0.7	0.95	1.1	1.4	1.7	2.0	2.3	2.5	2.7	2.9	3.1
25	0.01	0.04	0.05	0.01	0.01	0.09	0.20	0.34	0.51	0.73	1.24
31	0.02		0.01	0.01	0.02	0.06	0.11	0.23	0.29	0.79	1.15
68	0.02		0.03		0.05	0.07	0.11	0.17	0.34	0.75	1.31
70	0.00		0.01		0.02	0.05	0.08	0.18	0.25	0.62	1.09
102	0.00		0.02		0.01	0.02	0.02	0.03	0.11	0.41	0.69
108	0.00		0.00		0.00		0.00	0.01	0.08	0.30	0.63
112	0.00		0.02		0.01		0.01		0.06	0.25	0.51
135	0.00	0.01	0.06	0.10	0.16	0.21	0.37	0.85	1.25	1.73	
144		0.02	0.05	0.10	0.18	0.40	0.71	0.14	1.69		

LITERATURE

(For a key to the periodicals see end of volume)

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CHEMICAL DURABILITY OF GLASSES

W. E. S. Turner

Introduction

In the measurement of the durability of glasses, results may be duplicated with an accuracy of 5 to 10% only. In a series of glasses of similar composition, the results with the more durable glasses may be reproduced with an accuracy of 5%; the less durable, up to about 10%.

Introduction

Les résultats ne peuvent être reproduits, dans les mesures de durabilité des verres, qu'avec une précision de 5 à 10% seulement. Dans les séries de verres de composition similaire, les résultats concernant les verres les plus durables peuvent être reproduits avec une précision de 5%; ceux relatifs aux verres les moins durables, jusqu'à environ 10%.

Einleitung

Die Messungsergebnisse über die Dauerhaftigkeit der Gläser lassen sich nur mit einer Genauigkeit von 5 bis 10% angeben. In einer Reihe von Gläsern ähnlicher Zusammensetzung können die Ergebnisse mit dauerhafteren Gläsern auf 5%, mit weniger dauerhaften bis gegen 10% Genauigkeit angegeben werden.

Introduzione

I risultati ottenuti nelle misure di resistenza chimica dei vetri, sono riproducibili con una approssimazione del 5–10% soltanto. In una serie di vetri di composizione simile, i valori riferentisi ai vetri più resistenti sono riproducibili con l'approssimazione del 5%, e quelli riguardanti i vetri meno resistenti con una approssimazione del 10%.

EFFECT OF COMPOSITION

Table 1.—Fused-quartz Glass

Milligrams loss in wt. sustained in each test by a 76 cm^3 quartz flask, with 89 cm^2 surface exposed, when subjected in succession to the following reagents under the conditions shown ([35]); *cf.* ([53]).

Reagent, time and temperature			Loss mg
H_2O, 18°–100°	Many	Days at 18°	0.0
10% NH_3	2		0.8
10% NaOH	2		0.4
30% NaOH	2		0.0*
30% KOH	4		1.2†
2*N* NaOH	3	Hours at 100°	48
2*N* Na_2CO_3	3		12
2*N* KOH	3		31
2*N* NaOH	3		33
2*N* Na_2CO_3	3		8
2*N* KOH	3		64
2*N* NaOH	3		
N NaOH	14	Hours at 18°	2
N NaOH	14		1.8
N Na_2CO_3	14		0.6
Satd. $Ba(OH)_2$	14		0
Satd. Na_2SO_4	14		0
N H_3PO_4	14		0
10% NH_3	14		0
25% NH_3	60		0
25% NH_3, Fresh flask. Up to 60° with 4 renewals of reagent during experiment, 6 hrs			2.6

* No adsorption of NaOH.
† Adsorbed KOH difficult to remove by washing.

Remarks: $Ba(OH)_2$, 6 mo. at 18°, small crystals of Ba silicate formed. H_3PO_4 at 400°, extensive corrosion with formation of silicyl phosphate. *Dilute acids* in general, and conc. H_2SO_4, 18–100°, no action. Aqueous *methylene blue, congo red,* and *rhodamine;* ethereal *iodoeosin;* and alcoholic *aniline blue;* all slightly adsorbed but removable by hot solvents.

Table 2.—CaO · SiO_2 Wollastonite

Milligrams oxides extracted from 2 g by acids ([17, 30, 33, 38]).

Oxide \ Acid	30 min at 18°			2 hrs at 50°–60°	
	2*N* Acetic	0.1*N* HCl	2*N* HCl	2*N* HCl	10*N* HCl
mg CaO	0.010	0.017	0.11	0.70	0.76
mg SiO_2	0.000	0.004	0.040	0.26	0.020

3- (or 4-) Oxide Glasses

Table 3

Grams H_2SO_4 equivalent to the alkali extracted by water at 80° acting for 1 hr on glass powder, size <160 mesh/in. ([38, 41, 42, 43])

1. Molecular composition: $100SiO_2 + 40R_2O + xRO$

x	$40Na_2O + xCaO$	$40K_2O + xCaO$	$20Na_2O + 20K_2O + xCaO$	$40Na_2O + xPbO$	$40K_2O + xPbO$	$20Na_2O + 20K_2O + xPbO$	$40Na_2O + xBaO$	$40K_2O + xBaO$	$20Na_2O + 20K_2O + xPbO$
5	18.4	28.3	30.2	31.6		31.2	37.7	34.0	34.0
10	9.0	27.6	15.3	9.3		19.0	4.54	31.2	21.6
15	4.3	20.4	4.42	4.2		18.2	4.44	27.8	7.6
20	3.7	8.6	3.26	3.4	23.0	6.6	4.25	24.6	6.2
30	2.3	5.1	2.08	1.68	19.0	3.2	1.85	17.4	3.8
40	1.06	2.2	1.05	1.04	8.9	1.50	1.08	9.5	2.8

TABLE 3.—(*Continued*)

2. Molecular composition: $100SiO_2 + 20R_2O + xRO$

x	$20Na_2O + xCaO$	$20K_2O + xCaO$	$10Na_2O + 10K_2O + xCaO$	$20Na_2O + xPbO$	$20K_2O + xPbO$	$10Na_2O + 10K_2O + xPbO$	$20Na_2O + xBaO$	$20K_2O + xBaO$	$10Na_2O + 10K_2O + xPbO$
5	3.03	5.4	1.99		9.6	3.32		10.4	2.44
10	1.34	1.44	0.94	0.69	3.7	1.15	1.20	2.01	1.50
15	0.66	0.96	0.66	0.51	1.61	0.68	1.07	1.76	1.21
20	0.40	0.60	0.40	0.37	0.60	0.37	0.87	1.08	1.03
30	0.34	0.36	0.26	0.140	0.26	0.16	0.55	0.74	0.87
40	0.25	0.30	0.24	0.091	0.15	0.12	0.50	0.64	0.68

TABLE 4

Grams oxide extracted by water at 100° acting for 5 hr on 100 g glass powder, containing 7300 to 7624 particles per cm^3 (30, 32).

Molecular composition: $6SiO_2 + (2 - x)R_2O + xRO$

Oxide extracted \ Comp. $6SiO_2$ +	$2Na_2O$	$2K_2O$	$1.75Na_2O + 0.25CaO$	$1.75K_2O + 0.25CaO$	$1.5Na_2O + 0.5CaO$	$1.5K_2O + 0.5CaO$	$1.25Na_2O + 0.75CaO$	$1.25K_2O + 0.75CaO$	$Na_2O + CaO$	$K_2O + CaO$
R_2O	4.4	12.6	1.07	8.84	0.18	0.83	0.06	0.14	0.02	0.03
SiO_2	11.3	22.6	1.60	15.82	0.04	0.34	0.03	0.03	0.02	0.02
Total	15.7	35.2	2.67	24.66	0.22	1.17	0.09	0.17	0.04	0.05

TABLE 5

Grams of oxides extracted at 100° in 5 hr by the action of 60 cm^3 H_2O on powdered glass, 4000 particles per cm^3 (21, 22, 58).

Molecular composition: $xSiO_2 + yR_2O + zRO + wR_2O_3$

Composition. Wt. %					Grams oxide extracted			
SiO_2	Na_2O	RO		$Al_2O_3 + Fe_2O_3$	SiO_2	Na_2O	RO	Total
73.7	22.5			4.0	4.25	1.47		5.80
69.6	22.0	5.1	SrO	3.5	1.84	0.716	0.0191	2.60
70.0	17.7	9.9	SrO	2.7	0.061	0.098	trace	0.159
68.0	14.8	15.7	SrO	1.7	0.024	0.035	trace	0.058
66.7	11.8	19.6	SrO	1.9	0.0134	0.018	trace	0.031
69.6	19.3	7.6	BaO	3.8	2.74	0.97	0.0515	3.82
67.5	16.2	14.2	BaO	2.4	0.236	0.168	trace	0.415
62.2	9.6	25.6	BaO	2.9	0.026	0.109	trace	0.134

TABLE 6

Per cent Na_2O extracted by boiling water in 1 hr acting on powdered glass, 20–30 mesh (I. M. M. sieves, *v.* p. 329) (11, 12, 44, 47, 48, 49).

Molecular composition: $100SiO_2 + (33.3 - x)Na_2O + xRO$ (R_2O_3 or RO_2)

x \ R_aO_b	CaO	MgO	Al_2O_3	TiO_2	ZrO_2	ZnO	BaO
0.5							
1.0					4.4		
2.0	8.20			1.54	1.8	7.18	17.60
4.0	2.35	1.39	0.59	0.27	0.38	1.57	5.50
6.0	1.00	0.76	0.24	0.13	0.19	0.30	1.90

TABLE 6.—(*Continued*)

x \ R_aO_b	CaO	MgO	Al_2O_3	TiO_2	ZrO_2	ZnO	BaO
8.0	0.50	0.29	0.09	0.07		0.18	0.68
10	0.25	0.13	0.03	0.045		0.12	0.22
12	0.10	0.07		0.03		0.06	0.12
14	0.05	0.048		0.02		0.04	0.06
16	0.04	0.028		0.012		0.02	0.04
18	0.02	0.020		0.010			
20				0.008			

TABLE 7

Per cent loss in weight in 1 hr in boiling 20.24 % HCl, 2*N* NaOH and 2*N* Na_2CO_3 acting on powdered glass 20–30 mesh (I. M. M. sieves) (12).

Molecular composition: $100SiO_2 + (33.3 - x)Na_2O + xRO$

	x	2	4	6	8	10	12	14	16	18	20
HCl	CaO		8.2	4.2	2.6	1.7	1.2	1.0	1.0		
	MgO		1.4	0.7	0.4	0.3	0.2	0.2	0.1		
	Al_2O_3		0.9	0.4	0.2	0.2					
	TiO_2	2.0	1.0	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1
	ZrO_2	1.8	0.6	0.4							
	ZnO	1.8	0.9	0.5	0.3	0.2	0.2	0.1	0.1		
	BaO	9.6	2.0	1.0	0.5	0.3	0.2	0.2	0.2		
NaOH	CaO		2.6	2.3	2.1	2.0	1.7	1.5	1.2		
	MgO		3.1	2.8	2.5	2.7	2.1	2.1	2.1		
	Al_2O_3		2.8	2.5	2.5	2.6					
	TiO_2		6.0			3.6	3.2	2.9	2.6	2.4	2.3
	ZrO_2	1.3	0.8	0.7							
	ZnO	3.7	3.2	2.8	2.4	2.2	2.1	1.9	1.7		
	BaO	5.6	3.8	3.0	2.5	2.3	2.2	1.9	1.7		
Na_2CO_3	CaO		6.8	2.8	2.4	2.0	1.9	1.5	1.3		
	MgO			4.1	3.2	2.5	2.1	2.0	1.9		
	Al_2O_3		1.0	0.6	0.4	0.4					
	TiO_2	11.3	2.4	1.6	1.1	0.9	0.8	0.7	0.7	0.6	0.5
	ZrO_2	2.0	0.9	0.6							
	ZnO	11.2	2.5	0.5	0.4	0.3	0.2	0.2	0.2		
	BaO	38.0	7.0	4.9	4.0	3.5	3.2	2.6	2.2		

TABLE 8

Grams H_2SO_4 equivalent to alkali extracted by water at 80° acting for 1 hr on 100 g glass powdered to pass 160 mesh sieve.

1. Composition: $(70 - x)\%\ SiO_2 + x\%\ RO + y\%\ R_2O$ (39, 42)

x	RO	$25Na_2O$	$25K_2O$	$12.5Na_2O + 12.5K_2O$	$20Na_2O$	$20K_2O$	$10Na_2O + 10K_2O$
5	CaO	5.32	4.50				
	PbO	34.2	17.5				
	BaO	34.5	21.1	28.2			
10	CaO				1.64	0.75	0.67
	PbO				9.23	11.4	11.5
	BaO	28.8	18.6	22.9	13.3	9.64	7.40
15	CaO	1.98	1.00		1.12	0.60	0.49
	PbO	23.1	17.7		9.81	6.65	3.92
	BaO	22.6	15.8		10.4	7.11	4.87
20	CaO				0.72	0.51	0.40
	PbO				7.89	7.78	3.52
	BaO				8.93	3.47	2.99
25	CaO						
	PbO						
	BaO	14.0	12.7				

TABLE 8.—(*Continued*)

x	RO	25Na_2O	25K_2O	12.5Na_2O + 12.5K_2O	20Na_2O	20K_2O	10Na_2O + 10K_2O
30	CaO						
	PbO				4.88	4.61	3.17
	BaO				2.99	1.77	1.45
40	CaO						
	PbO				4.05	6.65	2.79
	BaO						
50	CaO						
	PbO				4.61	9.16	3.92
	BaO						

x	RO	15Na_2O	15K_2O	7.5Na_2O + 7.5K_2O	10Na_2O	10K_2O	5Na_2O + 5K_2O
15	CaO	0.44	0.240	0.22			
	PbO	2.91	1.696				
	BaO	2.68	1.371	1.28			
20	CaO	0.57	0.277		0.29	0.173	0.156
	PbO	2.54	1.610				
	BaO	2.09	0.998				
25	CaO						
	PbO	2.12	.848				
	BaO	1.66					
30	CaO						
	PbO				.45	.208	
	BaO				.68	.575	.337
35	CaO						
	PbO	1.40	.798				
	BaO	1.37					
40	CaO						
	PbO				.30	.163	
	BaO				.69	.563	.536
45	CaO						
	PbO	1.40	.845				
	BaO						
50	CaO						
	PbO				.24	.157	
	BaO						

TABLE 8.—(*Continued*)

2. Composition: $y\%$ SiO_2 + $z\%$ PbO + $(a - x)\%$ Na_2O + $x\%$ K_2O (19, 40)

a	y	z \ x	0.0	2.5	5	7	7.5	10	14	15	17.5	20
20	60	20	7.9		4.9			3.5	1.68	2.08	3.8	7.8
20	50	30	4.8		3.6			2.31	1.50	1.63	3.00	4.5
10	60	30	0.43	0.32	0.19	0.122	0.136	0.28				
10	50	40	0.30	0.21	0.123	0.069	0.128	0.175				

TABLE 9

Per cent Na_2O extracted by boiling H_2O and % loss in weight by action of boiling 20.24% HCl, 2N NaOH and 2N Na_2CO_3 solns. resp. Time 1 hr. 20–30 mesh powder. The final glasses contained 0.08–0.2% CaO and 0.05–0.14% Fe_2O_3 (12, 49, 50).

Batch	Analytical %				% Na_2O by H_2O	% loss in wt. by		
	SiO_2	B_2O_3	Na_2O	Al_2O_3		HCl	NaOH	Na_2CO_3
$(80 - x)\%$ SiO_2 + $x\%$ B_2O_3 + 20% Na_2O	79.8		19.5	0.69	2.11	1.40	2.92	6.35
	74.2	4.5	19.8	0.93	0.16	0.33	3.16	2.73
	71.6	8.3	18.8	1.00	0.06	0.31	3.10	2.64
	68.3	11.4	19.0	1.09	0.04	0.30	3.46	3.16
	64.7	14.5	20.0	0.71	0.07	1.02	4.54	3.70
	61.3	18.8	18.9	0.74	0.14	7.36	5.65	3.84
	50.0	28.8	20.4	0.78	2.25	39.4	17.2	17.1
	35.2	40.0	23.7	0.84	11.6	38.9	69.7	45.6
	32.2	43.7	23.1	0.82	14.7	39.1	94.6	56.1
$(90 - x)\%$ SiO_2 + $x\%$ B_2O_3 + 10% Na_2O	74.9	12.5	11.3	0.92	0.004	0.09	3.11	1.40
	70.8	18.7	9.8	0.79	0.07	0.67	4.73	3.10
	67.2	21.8	10.1	0.88	0.36	2.73	7.01	4.29
	62.0	25.8	11.2	0.84	0.89	32.7	22.1	15.2
	57.9	31.3	9.6	0.98	2.42	41.0	62.1	38.6
	52.1	36.2	10.3	0.89	5.50	49.0		54.3
	46.3	42.3	10.4	0.80	7.46	49.3		64.4
	41.3	46.1	11.5	0.80				72.8

MULTI-OXIDE GLASSES. APPARATUS GLASS

In the tables of durability data for these glasses, the glasses are identified by means of the Index Numbers (I. N.) given in Table 10. Additional literature (1, 6, 10, 14, 18, 20, 23, 24, 25, 31, 32, 34, 35, 36, 54, 55, 57).

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES SiO_2

I. N.	Origin	B_2O_3	As_2O_5	Sb_2O_3	$Al_2O_3+Fe_2O_3$	CaO	MgO	ZnO	PbO	Na_2O	K_2O	MnO	Lit.
C/1		14.37			4.09					14.79		0.06	(18)
C/2					2.84	10.31		5.07		13.06		0.35	(18)
C/3					0.23	14.68				9.70	4.87		(18)
C/4					0.46	13.28				8.47	5.49		(18)
C/5					0.30	13.95				8.07	5.15	0.22	(18)
C/6					0.23	11.37				10.54	5.85		(18)
C/7					0.39	10.84				6.32	10.03		(18)
C/8					0.23	10.77				12.48	3.53		(18)
C/9					0.30	10.68				12.67	3.80		(18)
C/10		2.55			2.18	8.82		7.65		20.09			(18)
C/11					2.42	16.99				19.62	0.54	0.48	(18)
C/12					0.15	7.87				1.22	11.31	0.11	(18)
C/13					1.05	16.14				17.12	1.57		(18)
C/14					0.32	9.83				11.77	8.35	tr.	(18)
C/15					2.74	11.19				19.26	6.20	0.29	(18)
C/16									14.09		14.13		(18)
C/17					2.03	8.57				17.77	4.84	0.46	(18)
C/18					0.39	11.48				7.20	9.87		(15)
C/19					1.44	21.92			0.85	16.78	0.64		(15)
C/20			0 1			BaO 2.91			16.87	0.89	8.87	0.02	(15)

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES SiO_2.—(*Continued*)

I. N.	Origin	B_2O_3	As_2O_5	Sb_2O_3	$Al_2O_3+Fe_2O_3$		CaO	MgO	ZnO	PbO	Na_2O	K_2O	MnO	Lit.
C/21					2.39		10.12				17.13	6.11	0.45	(15)
C/22					0.47		11.52				15.35	4.63		(14)
C/23					0.75		14.34				14.47	7.91		
C/24					2.54		11.69				17.66	6.78		
C/25					3.04		10.62				24.18	2.20		
C/26	Jena 1914	13.3			5.7		0.13	0.29	13.5		11.00	tr.	tr.	(4)
C/27	Jena 1914	14.55			3.99		0.89		12.86		11.95			(26, 27)
					Al_2O_3	Fe_2O_3								
C/28	Jena 1920	5.33			6.8		1.28		BaO 2.33		6.3	0.47		(26, 27)
C/29	British 1916*	2.6			8.3		12.40	0.20			20.20	4.00		(4)
C/30	British 1916*	9.4			5.6	0.05	0.64	tr.	10.3		17.40	0.33		(4)
C/31	Duroglass 1916*	5.9			5.9	0.04	7.00	0.8	4.0		16.80	2.50		(4)
C/32	Moncrieff 1916*	9.0			5.8	0.07	0.80	0.3	9.7		14.6	1.0		(4)
C/33	Wood Bros. 1916*	10.1			9.0	0.06	9.6	0.5			15.0	1.6		(4)
C/34	Poulenc Frères 1916	4.9			0.85	0.07	8.9	tr.	7.9		9.0	5.5		(4)
C/35	French 1916				0.75	0.05	11.8	1.1			23.6	0.6		(4)
C/36	Swedish 1916	2.5			0.9	0.08	7.8	0.3	3.2		20.3	1.2		(4)
C/37	Italian 1916	2.0			0.3	0.07	10.9	tr.			17.2	3.0		(4)
C/38	U. S. A. Nonsol 1917	9.5		0.13	2.25	0.11	1.25	7.5	8.05		17.0	0.28	tr.	(7)
C/39	U. S. A. Insolo 1917	4.95		0.3	0.8	0.18	2.6	13.45	4.05		15.5	0.64	tr.	(7)
C/40	U. S. A. Fry 1917	10.0	0.07		2.5	0.11	4.15	5.55	3.85		14.1	1.25	tr.	(7)
C/41	U. S. A. Pyrex 1917	12.6	0.23		1.45	0.07	0.3	0.5			4.6	0.5	tr.	(7)
C/42	U. S. A. Insol 1917	2.9		0.2	0.57	0.12	5.0	10.05	8.95		14.3	2.9	tr.	(7)
C/43	Macbeth-Evans 1919	9.03	0.02	0.11	1.30	0.18	0.96	5.47	5.50		14.65	0.27	tr.	(7)
C/44	Greiner & Friedrich Resistance "R"	4.8		0.47	2.75	0.08	0.33	7.4	9.15		17.05	1.35		(7)
C/45	Köln-Ehrenfeld	5.45	0.82	0.4	2.25	0.12	2.85	5.9	10.9		10.8	1.7	tr.	(7)
C/46	Kavalier 1917		tr.		0.18	0.05	12.4	0.3			9.35	6.65	tr.	(7)
C/47	German (unmarked)				0.21	0.07	8.95	0.57			14.3	4.75		(7)
C/48	Hungarian (Zsolna)				0.23	0.07	12.6	tr.			9.0	6.4	tr.	(7)
C/49	Japanese 1917				1.9	0.07	5.3	0.22			22.6	1.2		(7)
C/50	Murano 1922	13.63			5.61		1.62		11.17		8.79			(26, 27)
C/51	Murano 1923 No. 1	10.28			4.71		8.57				5.16			(26, 27)
C/52	Murano 1923 No. 2	10.99			3.62		3.30				5.21			(26, 27)
C/53	Murano 1923 No. 3	11.81			2.94						5.56			(26, 27)

* Most of the glasses of these makes have been modified and improved since 1916.

TABLE 11.—ACTION OF WATER ON FLASKS

The values given are thousandths mg alkali extracted and mg loss in weight, each for 100 cm² surface. The autoclave data at 190° and at 183° respectively are not comparable with one another.

I. N. (17, 28)	Alkali extracted 10^{-3} mg		Autoclave mg loss 4 hr 190°	I. N. (17, 28)	Alkali extracted 10^{-3} mg		Autoclave mg loss 4 hr 190°
	8 da 20°	3 hr 80°			8 da 20°	3 hr 80°	
C/1	2.5	2.7	23.7	C/9	17.8	66	67.0
C/2	2.1	6.3		C/10	16.6	65	34.0
C/3	10.7	28.4		C/11	27.0	98	
C/4	8.9	28.2	17.2	C/12			63.0
C/5	13.1	26.8		C/13			37.0
C/6	14.0	56		C/14	32.0	217	
C/7	14.5	45	51.3	C/15	77.0	654	126
C/8	14.9	50		C/16	74.0	356	
C/46	12.5	24.6	(7)	C/48	13.6	29.3	(7)

TABLE 11.—ACTION OF WATER ON FLASKS.—(*Continued*)

I. N. (4)	Alkali extracted 10^{-3} mg		Milligrams loss in weight				
			3 hr steam Treatments			2 hr evap. 100°	Autoclave 3 hr 183°
	8 da 20°	3 hr 80°	1st	2nd	3rd		
C/26	1.6	1.9	0.30	0.15	0.05	0.6	26.0
C/29	3.7	7.0	0.30	0.10	0.08	0.9	22.0
C/30	3.1	5.6	0.28	0.15	nil	0.6	23.7
C/31	2.6	6.2	0.25	0.12	0.08	1.05	26.8
C/32	2.3	4.7	0.22	0.04	nil	0.45	20.7
C/33	2.5	4.9	0.25	nil	nil	0.67	18.5
C/34	3.3	6.3	0.24	0.40	0.16	0.52	20.5
C/35	25.7	43.2	4.00	2.23	2.12	8.6	2210
C/36	12.3	24.7	2.13	1.85	1.24	2.1	875.0
C/37	21.7	35.4	2.30	1.75	1.43	4.7	1040

Table 11.—Action of Water on Flasks.—(*Continued*)

I. N.	mg loss in weight: 2 hr evap. 100°	mg loss in weight: Autoclave 3 hr 183°	I. N.	mg loss in weight: 2 hr evap. 100°	mg loss in weight: Autoclave 3 hr 183°
C/38	0.8	31.5	C/44	1.05	55.4
C/39	1.05	139	C/45	1.0	48.5
C/40	0.95	48.7	C/46	2.6	614
C/41	0.67	10.0	C/47	0.4	3183
C/42	1.0	79.6	C/48		
C/43	0.3	46.2	C/49	5.4	
Lit.	(7, 24, 29)				

Table 12.—Action of Acids on Flasks

Mean loss in wt. (mg per 100 cm^2 surface) from 3 successive treatments with each reagent. Reagents: A, HCl vapor for 3 hr (4). B, 20.24% HCl evap. for 1.5 hr (4, 7). C, $2N$ H_2SO_4 for 6 hr at 100° (17). D, concd. H_2SO_4 heated to fuming for 4 hr (51). E, 1.2 sp. gr. HNO_3 evap. for 1.5 hr (28, 29, 51). (*Cf.* Tables 15, 16, 18, and 20.)

R \ I. N. C/	26	29	30	31	32	33	34	35	36	37
A	1.59	1.01	0.52	0.36	0.63	2.60	0.37	0.71	0.39	0.73
B	10.6	5.0	3.2	2.4	2.7	11.1	1.7	2.7	1.9	1.8
C	1.2	0.8	0.9	1.3	0.8	0.8	0.8	1.9	1.9	1.3
D				1.0		0.2		1.0		
E					1.0	1.8	1.6			

R \ I. N. C/	38	39	40	41	42	43	44	45	46	47
B	1.0	1.0	1.1	0.5	1.1	0.5	0.9	1.4	0.7	0.2

Table 13.—Action of Alkalies on Flasks

Loss in wt., mg/100 cm^2 surface.

Reagents: A, $2N$ NaOH for 3 hr at 100° (17). B, $0.1N$ NaOH for 3 hr at 100° (17). C, $2N$ NH_4OH evap. for 65–70 min (17). D, $2N$ Na_2CO_3, 3 hr at 100° (17). E, $2N$ $(NH_4)_2S$ 3 hr at 100° (4, 7, 50). F, Na_2HPO_4 3 hr at 100° (28, 29, 50).

From No. 26 onwards in the case of the sodium hydroxide, ammonia and sodium carbonate tests the values quoted are the mean of three successive treatments.

R \ I. N. C/	1	2	3	4	6	7	8	9	10	11	15	16
A	67.3	39.7	35.4	37.5	39.8	37.7	38.5	42.4	46.5	31.3	46.0	58.0
D	23.5	17.6		59.5	76.9	79.2	73.0	79.4	23.0	40.7	45.0	51.0

R \ I. N. C/	26	29	30	31	32	33	34	35	36	37
A	129.2	92.2	97.4	79.8	94.6	104	78.6	157	114	121
B	21.4	20.0	20.7	18.0	20.6	17.5	15.3	45.6	30.2	37.1
C	3.2	4.5	2.7	3.0	2.9	2.6	2.4	7.2	4.9	5.6
D	30.7	30.1	27.7	24.7	26.0	27.7	36.0	200	87.8	121
E					1.0		1.2	1.1		
F, $0.5N$						2.8	2.0	7.3		
F, $0.25N$						1.6	1.2	5.3		

R \ I. N. C/	38	39	40	41	42	43	44	45	46	47
A	95.7	98.0	93.6	118	79.8	82.3	79.1	81.0	96.4	91.2
B	17.7	21.4	18.8	30.7	15.5	18.6	21.8	13.7	28.1	32.8
D	29.2	48.5	36.0	51.1	32.3	29.1	26.0	25.3	141	132

Table 14

Action of Na_2CO_3 and K_2CO_3 solutions for 3 hr at 100° and of water and NaOH for 50 days at room temperature. Loss in wt., mg/100 cm^2 (14).

I. N.	Na_2CO_3 g/l		K_2CO_3 g/l	NaOH g/l				H_2O†	
	13.2	132	172	10*	10†	100*	100†	*a*	*b*
C/22	46.4	75.8	48.1	3.9	4.6	5.2	5.7	6.6	6.0
C/23	49.5	83.3	52.8	4.5	5.1	6.3	6.2	16.5	12.6
C/24	26.3	45.2	21.2	5.1	6.4	6.0	6.7	23	22.5
C/25	24.8	41.2	20.0	5.5	5.0	6.6			

* Successive treatments of same flask.

† *I.e.*, alkali extracted by water in 50 days from (*a*) new flasks, (*b*) flasks pretreated with the 100 g/l NaOH for 100 days.

Table 15.—The Effect of Boric Oxide

Mg loss in wt. by 500 cm^3 flasks. Reagent: (1), N HCl boiling for; A, 0.5 hr; B, 2 hr; C, $0.1N$ HCl autoclave 3 hr. (2), $0.01N$ NaOH boiling for: D, 0.5 hr, E, 2 hr, F, $0.1N$ NaOH autoclave 3 hr at 120° (25, 26).

I. N. \ R	A	B	C	D	E	F	I. N. \ R	A	B	C	D	E	F
C/27				3.2	10.0	81	C/41	0.30	2.0	2.0	6.0	19.5	229
C/28	0.35	2.0	2.1	4.5	11.0	123	C/51	0.34	2.6	2.3	4.3	10.5	94
*	0.33	2.5	2.2	4.5	10.7	108	C/52	0.33	2.5	2.2	4.5	10.7	108
C/50	0.50	3.1	2.5	2.5	9.0	81	C/53	0.31	2.0	2.0	6.0	19.1	200

* Murano 1923, white badge.

Table 16

Per cent loss in weight in 1 hr by boiling water, 20.24% HCl, and $2N$ NaOH, respectively, acting on 20–30 mesh powdered glass (46, 52).

Wt. % composition: $(75.8 - x)SiO_2 + xB_2O_3 + 8.6CaO + 6.9Na_2O + 7.9K_2O + 0.66R_2O_3$

x	H_2O	HCl	NaOH	x	H_2O	HCl	NaOH
0	0.060	0.056	1.50	12.5	0.085	1.45	2.32
0.5	0.060	0.056	1.45	15.0	0.105	7.40	2.70
1.0	0.060	0.056	1.45	20.0	0.170	29.8	3.95
2.5	0.060	0.056	1.46	25.0	0.485	47.2	5.65
5.0	0.060	0.060	1.55	30.0	1.150	54.80	8.00
7.5	0.062	0.090	1.75	35.0	2.175	59.4	13.5
10	0.068	0.300	2.00	40.0		62.6	25.5

Table 17.—Action of Neutral Salt Solutions

mg/100 cm^2 loss in wt. in 3 hr at 100°

	Na_2SO_4, 178 g/l (14)				5% NH_4Cl, mean, 3 successive treatments (4)								
I.N.C/	22	23	24	25	26	29	30*	31*	32	33	34*	36	37
mg	1.8	3.1	1.6	2.3	0.25	0.28	0.28	0.23	0.40	0.28	0.16	0.29	0.39

* No loss on 3rd treatment.

Table 18.—The Influence of Reagent Concentration

mg/100 cm^2 loss in wt. (14, 15)

6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/8	14	15
H_2SO_4	0.001	0.2	1.1	1.7	HCl	0.001			1.5
	0.1	0.1	1.0	1.5		0.1	0.2	0.9	1.6
						1	0.3	1.1	1.9
	1	0.2	1.2	1.7		2	0.3		1.8
	5	0.2	1.0			4			1.7
	10	0.3	0.9	1.7	$C_2H_4O_2$	0.1	0.2	0.8	1.6
	25	0.1	0.2	0.5	Acetic	1	0.2	0.8	1.7
(Sp. gr.	= 1.84)	0.1	0.1	0.2	acid	5	0.1		1.4

TABLE 18.—THE INFLUENCE OF REAGENT CONCENTRATION.—(*Continued*)

mg/100 cm^2 loss in wt. (14, 15)

6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/16	19	20
HNO_3	0.1	0.2	1.2	1.7	HCl	1	1.2	0.3	1.4
	1	0.2	0.7	1.8		5	1.3		
	5	0.1	1.0	1.5	$C_2H_4O_2$	1	0.9		
	10	0.4	1.2	1.5					
	16.5	0.2		1.0	H_2SO_4	1	1.2		

KOH g/l	Gls. C/25	14	140	210	280	420	490	Data for $6SiO_2 + (2-x)R_2O + xCaO$ in same paper (14)
mg loss, 3 hr 100°		17.5	28.0	28.3	27.2	23.6	24.6	

I. N.	KOH g/l, 3 hr at 100°		NH_4OH g/l (or wt. %), 50 days at room temperature			
	140	490	4.3	43	10%	25%
C/22	21.7	20.8*		3.5		0.9
C/23	23.3	21.1*	3.6	3.5	3.2	1.0
C/24	26.9	21.6	3.4	3.5	3.6	1.0
C/25	28.5	24.1*	3.2	3.5	4.1	0.9

* Mean of 2 determinations.

TABLE 19.—INFLUENCE OF REPEATED ACTION AND TIME

Continued action of H_2O at 20° on glass No. C/21 (16)

Time of treatment	mmg (= 10^{-6} g) Na_2O per 100 cm^2 dissolved from glass					
	1. In original condition	2. After 42 da in H_2O vapor at 30°	3. After 42 da in moist CO_2 at 30°	4. After 12 mo in air of room	5. After 12 mo in outdoor air	4 followed by 3
1 min	36	65	59	48	66	109
1 day	63	62	10	50	45	13
2 days	19		7	17	18	6
3 days	14	17	6	15	15	7
5 days	14	14		12	12	6
7 days	11	9		9	8	
10 days	8	8		8	8	7

TABLE 20

mg/100 cm^2 loss in wt. by successive treatments (8)

No. of treatments	2 hr evap. H_2O at 100°			1.5 hr evap. 20.24% HCl			3 hr at 100°, 2N NaOH			3 hr at 100°, 2N Na_2CO_3		
	C/31	33	35	26	31	35	31	33	35	32	33	35
1	0.6	1.2	12.2	7.0	2.1	3.75	68	86	160	25.7	26.2	85
2	0.7	1.65	8.7	9.1	2.9	2.25	75	97	143	21.7	26.1	121
3	0.75	1.8	5.6	8.8	2.4	1.5	68	97	124	20.0	30.1	135
4	0.9	1.7	5.2	9.0	2.1	1.35	83	86	131	22.6	27.0	135
5	0.2	0.08	2.4	8.8	2.0	0.9	75	111	132	22.8	28.3	157
6	0.3	0.3	2.3	10.2	2.2	1.05	78	99	120	24.8	29.8	137
7	1.05	1.5	3.4	8.5	2.0	1.3	77	97	130	22.6	25.3	130
8	0.9	1.4	2.6	9.6	2.2	1.1	74	117	137	23.2	27.3	181
9	0.15	0.9	2.8	9.9	2.3	1.2	67	110	121	22.6	25.7	154
10	0.08	0.8	4.4	10.9	2.2	1.3	75	100	153	21.8	27.7	163
11				10.4	2.2	1.2				21.9	24.5	138
12				8.8	2.0	0.9				21.8	25.2	145
13				11.0	1.75	0.7				21.6	27.3	133
14					2.25	0.6				20.3	23.5	149
15					2.0	0.9				20.4	23.7	141

TABLE 20.—(*Continued*)

mg/100 cm^2 loss in wt. by successive treatments (8)

20.24% HCl evaporating for 1.5 hr

No. of treatments	16	17	18	19	20	21	22	23	24	25
Index No. C/31	2.1	2.1	1.35	1.75	1.8	1.75	2.7	1.8	1.8	2.0
Index No. C/35	1.1	1.05	0.3	0.15	0.3	0.3	0.9	0.45	0.6	0.45

TABLE 21.—THE INFLUENCE OF TEMPERATURE

Amount extracted per 100 cm^2 surface

Alkali extracted (14)							mg matter extracted (9)				
	By H_2O		Na_2CO_3, 132 g/l		K_2CO_3, 172 g/l		H_2O for 24 hr 250 cm^3 flask				
Index No.	3 days room temp.	1 hr 80°	50 days room temp.	3 hr 100°	50 days room temp.	3 hr 100°	Index No.				
C/	10^{-6} g		10^{-3} g				C/	80°	90°	95°	100°
22	6.3	63	4.4	75.8	2.0	48.1	33		1.4	2.4	5.0
23	16.5	210	4.6	83.3	2.1	52.8	32		1.0	2.0	4.0
24	23	337	2.2	45.2	0.8	21.2	47		1.0	2.4	5.4
25	40	607	2.0	41.2	0.9	20.0	38	4.8	7.5	14.2	55.4

mg loss in wt. of 500 cm^3 flasks by 20.24% HCl for 12 hr (9)

I. N. C/	90°	95°	99.9°	102°	104.8°
26	6.2	7.8	9.8	10.8	13.2
31	1.6	2.1	2.7	3.4	4.6
33	5.4	7.2	9.3	10.4	12.9

mg loss in wt. of 500 cm^3 flasks in 3 hr (5)

Index No. C/	By 2N NaOH					Index No. C/	By 2N Na_2CO_3				
	40°	60°	80°	90°	100°		40°	60°	80°	90°	100°
31	1.7	4.1	18.9	31.7	74.2	32		2.6	10.2	16.8	32.9
33	1.5	4.3	19.2	36.5	88.9	33		3.2	10.6	18.1	34.8
36			24.1	45.5	154	48	2.1	5.9	25.9	49.2	115

TABLE 22.—INFLUENCE OF CONCENTRATION, TIME AND TEMPERATURE

mg/100 cm^2 loss in wt. by action of commercially pure NaOH (C. P. NaOH somewhat less corrosive) (14)

NaOH g/l	Time	Temp. °C	Index No. C/ 22	23	24	25
1	*3 hours	100			18.3	
10	50 days	18	3.9	4.5	5.1	5.5
10	*3 hours	100	27.6	32.8	35.2	34.5
100	50 days	18	5.2	6.3	6.1	6.6
100	*3 hours	100	54.0	58.3	60.6	62.9
450	50 days	18	1.8	1.7	2.0	3.7
	*3 hours	100	46.6	52.5	52.7	52.8

* Not clearly stated in text, but assumed from reference from earlier page.

OPTICAL GLASSES

Table 23

Hundredths-milligrams of iodoeosin per 100 cm^2 surface ([2, 45])

Glass index No.	Type	n_D	Fractured surfaces: Fresh	Fractured surfaces: 7 da in moist air at 18°	Fractured surfaces: Fractured under the soln.	Fractured surfaces: Steamed 1 hr at 2 atm.	Fractured surfaces: Grade	Polished surfaces: Fresh	Polished surfaces: 7 da in moist air at 18°	Polished surfaces: Heated 4 hr 150°	Polished surfaces: Steamed 1 hr at 2 atm.
0/1	Fluor crown	1.4942	3	2	23		h^1	2	2	3	
2	Borosil. crown	1.5108	11	7	10	108	h^2	2	3	4	63
3	Borosil. crown	1.5135	8	3	18	106	h^1	3	3	4	65
4	Borosil. crown	1.5171	17	8	17	112	h^2	2	2	3	72
5	Hard crown	1.5173	16	7	8	181	h^2	4	6	9	155
6	Soft crown	1.5225	19	69	33		h^5	8	26	23	
7	Light Ba crown	1.5408	14	5	16	150	h^1	3	2	3	108
8	Medium Ba crown	1.5736	8	3	12	94	h^1	4	4	3	94
9	Dense Ba crown	1.6129	21	8	22	115	h^2	4	3	3	84
10	Dense Ba crown	1.6111	19	6	21	71	h^2	3	3	3	47
11	Dense Ba crown	1.6052	15	3	19	65	h^1	4	2	4	45
12	Telescope flint	1.5177	10	6	11	137	h^2	5	2	4	122
13	Light Ba flint	1.5655	10	3	13	55	h^1	4	4	3	37
14	Light Ba flint	1.5804	14	8	16	130	h^2	5	3	4	126
15	Light Ba flint	1.5282	10	2	11	164	h^1	4	2	3	140
16	Ba flint	1.6051	16	2	19	56	h^1	3	2	3	55
17	Extra light flint	1.5516	12	8	14	108	h^2	3	4	4	99
18	Light flint	1.5741	8	4	10	106	h^1	2	2	3	100
19	Light flint	1.5677	11	6	12	95	h^2	3	2	2	89
20	Dense flint	1.6174	24	6	20	86	h^2	3	2	2	85
21	Dense flint	1.6229	21	2	19	85	h^1	3	2	3	80
22	Extra dense flint	1.6521	26	1	20	69	h^1	2	1	1	58
23	Borosil. crown	1.5089	12	8			h^2				
24	Hard crown	1.5186	19	9			h^2				
25	Zinc crown	1.5160	11	5			h^1				
26	Light Ba crown	1.5040	22	3			h^1				
27	Medium Ba crown	1.5724	11	4			h^1				
28	Dense Ba crown	1.6087	24	9			h^2				
29	Dense Ba crown	1.6118	13	6			h^2				
30	Dense Ba crown	1.6129	14	5			h^1				
31	Light Ba flint	1.5515	12	2			h^1				
32	Dense Ba flint	1.6256	18	2			h^1				
33	Dense Ba flint	1.6683	19	2			h^1				
34	Extra light flint	1.5280	11	6			h^2				
35	Light flint	1.5789	17	2			h^1				
36	Dense flint	1.6039	19	6			h^2				
37	Dense flint	1.6221	20	4			h^1				
38	Extra dense flint	1.6475	20	2			h^1				
39	Densest extra large flint	1.7072	14	1			h^1				
40	Fluor crown	1.4933	4	2	4		h^1	2	3	3	
41	Borosil. crown	1.5100	17	8	17	107	h^2	3	4	4	87
42	Silicate crown	1.5144	28	20	34		h^3	4	17	18	
43	Ordinary sil. crown	1.5175	20	30	23		h^4				
44	Soft sil. crown	1.5151	41	58	48		h^5	5	25	24	
45	Light Ba flint	1.5646	15	5	16	102	h^1	3	2	2	86
46	Ordinary light flint	1.5800	14	7	16	104	h^2	3	2	3	81
47	Heavy flint	1.6190	23	2	19	80	h^1	2	2	2	71

Table 24.—Durability by Autoclave Treatment

Dimming test (appearance after weathering polished surface in air saturated with water vapor at 80° for 30 hr) and moisture retained by powdered glass. Grading by apparent effect of autoclave treatment: Grade 1 = least apparent effect. Grade 5 = greatest apparent effect. Dimming test: Three grades, 1, 2, 3. Symbols 1+ and 2− = rather worse than 1 and rather better than 2 resp. ([2, 13, 45]).

Glass ind. No.	Water for 4 hr at 4 atm.: Loss in wt. mg/100 cm^2	Water for 4 hr at 4 atm.: Iodo-eosin value of water extract	Water for 4 hr at 4 atm.: Grade by appear-ance	Grade by dim-ming test	mg H_2O retained per 100 g glass powder, 90–100 mesh: Dried in vacuo	mg H_2O retained per 100 g glass powder, 90–100 mesh: Heated to 120°C
0/1	127	182	5			
2	16.6	25.8	3	2	33	0
3	14.8	43.8	1			
4	10.9	41.3	1			
5	16.9	38.6	1	2−	135	87
6		1875	5	3−	230	151
7	21.7	38.0	3	1	9	0
8	10.5	31.4	3	1+	26	7
9	14.0	31.0	1	1+	26	7
10	11.5	19.7	4	2−	27	13
11	9.8	30.8	4			
12	8.6	21.9	4	2−	71	36
13	9.2	20.9	4	1+	28	12
14	8.5	18.9	4	2−	53	17
15	5.8	30.0	2			
16	6.1	11.5	3			
17	2.7	15.5	2			
18	3.7	10.4	2			
19	3.2	8.5	1	1	43	27
20	4.7	4.2	2	1+	28	16
21	3.2	3.4	2			
22	4.8	6.3	2			
23	27.2	73.2	2			
24	17.3	61.7	2			
25	13.7	31.7	4			
26	18.8	48.0	4			
27	11.0	31.7	3			
28	8.4	24.9	3			
29	9.2	20.7	3			
30	9.0	28.9	1			
31	5.3	18.5	2			
32	2.6	3.5	3			
33	2.8	4.3	3			
34	3.5	19.6	4			
35	2.4	7.7	1			
36	3.8	6.1	2			
37	2.7	2.7	1			
38	4.0	5.2	2			
39	1.3	1.6	1			
40	513	545	5			
41	21.6	63.6	3			
42	18.2	68.5	4			
43	12.9	63.4	4			
45	10.9	25.8	4			
46	3.3	9.4	3			
47	4.5	9.1	3			

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VITREOUS ENAMELS FOR METALS

RALPH R. DANIELSON AND H. G. WOLFRAM

COMPOSITIONS

1. Molecular Compositions

Type \ Component	Na_2O	K_2O	CaO	ZnO
Jewelry ([28])	0.3 –0.6	KNaO	0	0
Cast Fe ([3])	0.54	0.16	0.10	0.05
Cast Fe ([15])	0.70–0.74	0.06–0.11	0–0.19	0–0.2

Type \ Component	PbO	Al_2O_3	As_2O_3	Sb_2O_3
Jewelry ([28])	0.4–0.7	0	0.05–0.15	0
Cast Fe ([3])	0.15	0.16	F	0.075
Cast Fe ([15])	0	0.12–0.15	0.6 –0.86	0–0.13

Type \ Component	B_2O_3	SiO_2	SnO_2	P_2O_5
Jewelry ([28])	0–0.2	1.3 –1.8	0	0
Cast Fe ([3])	0.20	1.80	0	0
Cast Fe ([15])	0.68–1.14	0.64–0.77	0–0.34	0–0.43

2. Weight Per Cent

A = Jewelry enamels.
B = Single coat gray ware enamels.
C = Dry process white cover enamels for cast iron.
D = Single coat white enamel. Wet process for cast iron.
E = White cover enamels. Wet process for cast iron.
F = White cover enamels for sheet iron and steel.
G = Ground coats for sheet iron and steel.

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	K_2CO_3	KNO_3	Cryolite	CaF_2	Lit.
A	14.4			19.2		9.9		23.2			([30])
A	31.2	1.2			1.7	2.4	2.1	2.9			([8])
B		50.2	30.5		3.1	3.1			3.7	4.2	([1])
B	10.0	40.0	30.5		6.5	5.5				1.5	([6])

2. Weight Per Cent.—(*Continued*)

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	$BaCO_3$	KNO_3	Cryolite	CaF_2	Lit.
C		33.1	18.7		2.6	2.6	4.4		2.6	4.4	([26])
C		33.4	19.5	17.9		2.4			9.8		([26])
D	12.8	18.9	25.6						9.4	2.7	([24])
D		36.0	31.8		5.5	3.7	$CaCO_3$		3.2		([9])
E	10.2	32.3	20.8		3.3	5.3			4.3	4.7	([9])
F	17.0	31.0	27.0		3.5	3.5			12.0	5.0	([6])
F	22.0	31.0	21.0		3.5	3.5			17.0		([6])
G	20.5	27.0	30.0		9.8	5.0				6.0	([6])
G	21.0	26.0	34.6		7.4	4.0	2.2			3.5	([19])
G	29.0	22.0	30.0		5.0	4.6				6.0	([6])

Enamel \ Component	Bone ash	Pb_3O_4	ZnO	SnO_2	As_2O_3	Sb_2O_3	MnO_2	Ni_2O_3	Co_2O_3	Lit.
A		33.3								([30])
A		53.8			4.7					([8])
B	3.1					2.1				([1])
B	4.5					1.5				([6])
C		14.6	9.1	7.9						([26])
C			10.2	6.8						([26])
D		30.6								([24])
D		18.2				1.6				([9])
E		14.0	5.1							([9])
F						1.0				([6])
F						2.0				([6])
G							1.2		0.5	([6])
G							0.26	0.26	0.26	([19])
G							2.0	1.0	0.4	([6])

SPECIFIC GRAVITY

Ground coat for sheet steel 2.54. White cover enamel for sheet steel 2.66. High lead-tin oxide enamel for cast iron 2.93. Leadless antimony enamel for cast iron 3.32. High lead oxide enamel for jewelry 3.79 ([31]).

STRENGTH

Ultimate Compressive Strength (Def. 4)

Commercial ground coat for sheet steel, 95 500 lb./in.^{2}. Commercial white cover for sheet steel, 91 740 lb./in.^{2}. Cylindrical test pieces ½ in. diam. × 1 in. long ([11]).

Cross Bending Strength

See ([12, 20]).

Impact Resistance

See ([11, 17, 29]).

HARDNESS

See ([2]).

THERMAL EXPANSION OF VITREOUS ENAMELS

The coefficient of cubical expansion, $\frac{10^7 dV}{V\,dt}$, can be approximately calculated from the wt. % composition of the melted enamel and the moduli given below.

MODULI

AlF_3	Al_2O_3	As_2O_5	BaO	B_2O_3	BeO	CaO	CaF_2	CeO_2	CoO	Cr_2O_3	Cryolite	CuO	FeO
4.4	5.0*	2.0	3.0	0.1*	4.7	5.0* 4.9†	2.5	4.2	4.4	5.1	7.4	2.2	4.0

K_2O	MgO	MnO	NaF	Na_2O	NiO_2	PbO	Sb_2O_5	SiO_2	SnO_2	ThO_2	TiO_2	ZrO_2	ZnO
8.5*	0.1* 1.3_5†	2.2	7.4	10* 13†	4.0	4.2	3.6	0.8* 0.15†	2.0	6.3	4.1	2.1	1.8

* Values from Winkleman and Schott ([32]).
† Values from English and Turner ([13]).
All others from Mayer and Havas ([18]).

The calculation is illustrated in the following example and in the table of Expansion of Enamels.

Composition	Wt.		Moduli		
Silica	25.30	×	0.8	=	20.2
Alumina	7.20	×	5.0	=	36.0
Potassium oxide	6.60	×	8.5	=	56.1
Sodium oxide	8.94	×	10.0	=	89.4
Boric oxide	12.77	×	0.1	=	1.3
Barium oxide	6.21	×	3.0	=	18.6
Zinc oxide	14.00	×	1.8	=	25.2
Calcium oxide	1.68	×	5.0	=	8.4
Calcium fluoride	7.30	×	2.5	=	18.3
Antimony oxide	10.00	×	3.6	=	36.0
	100.00				309.5

The calc. cubical coefficient of expansion for this enamel is therefore 309.5×10^{-7} per °C.

Danielson and Souder ([10]) have shown, however, that values so calculated are only approximate. The following are typical:

Types of enamel	Coeff. of linear expansion × 10^6. Observed values				$\frac{10^6}{l}\frac{\Delta l}{\Delta t}$ Calculated values
	20° to 200°C	20° to 400°C	20° to 450°C	20° to 500°C	
Single coat gray ware	9.8	11.6		13.4	11.0
Ground coat for sheet steel	9.4	10.3	11.5		

The determinations made by Mayer and Havas were over the range 0–100°C while those made by Danielson and Souder were carried to the softening points of the enamels, *i.e.*, about 450° to 500°C. It will be noted that the coefficient rapidly increases with increase in temperature as shown by Fig. 1 ([10]).

The results of these various studies indicate that the factors given by Mayer and Havas place the oxides in approximately their correct order as regards their relative effect on the expansivity of enamels and may thus serve as a valuable guide in the technical control of enamel mixtures.

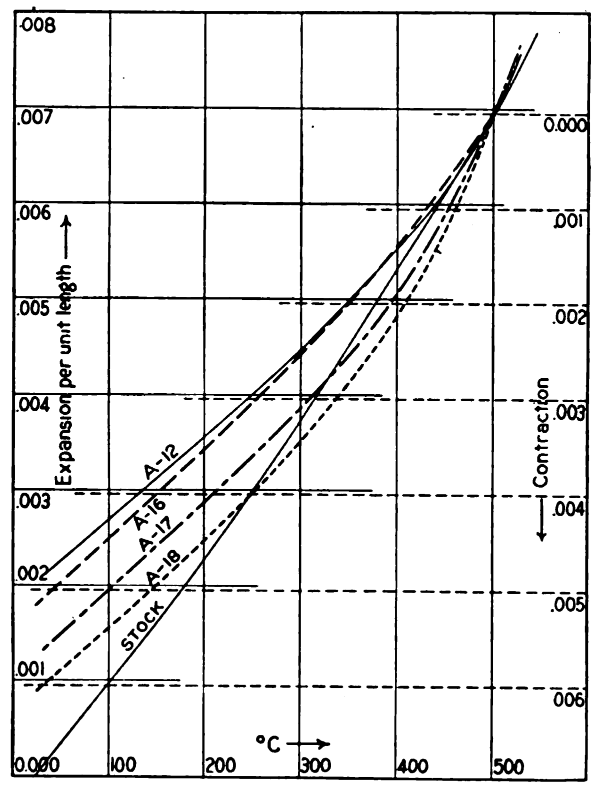

FIG. 1.—Expansion of some typical gray ware enamels and enameling steel.

From the observations of the various investigators it may generally be assumed that the average coefficients of expansion of commercial enamels and enameling metals will be within the following limits:

Type of enamel	$\frac{10^7 dV}{V\,dt}$
Ground coat for sheet steel	260 to 320
White cover enamel for sheet steel	320 to 400
White enamel for cast iron	290 to 330
White enamel for jewelry	300 to 350
Cast iron	310
Sheet iron and steel	381 to 438

For table of expansion of various enamels *v.* p. 116.

HEAT TRANSFER BY ENAMELED METALS

Observations on a large number of commercial steel enameled units led to the following over-all coefficients of heat transfer under the conditions named ([22]).

Operating conditions	Over-all coefficient joule $m^{-2}\,hr^{-1}$ (°C)
Steam, to cold water	1674 to 2929
Hot water, to cold water	1464
Steam, to boiling water	2929
Steam, to thick fruit product	669
Hot water, to cold water or brine	837 to 2510
Hot oil, to cold oil	271 to 586
Hot oil, to boiling water	628 to 837
Steam, to water in tubular heaters	2092 to 3347
Condensing steam to water in tubular condenser jacket	2929

Velocities of liquids over heating surfaces as affected by agitation, differences in mobility, and specific heat were involved in the above experiments.

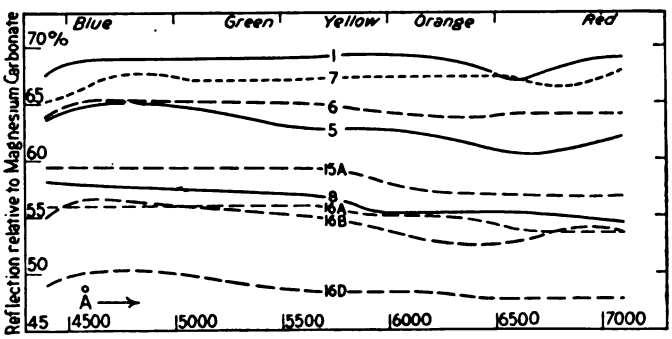

FIG. 2.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 7. Sodium antimonate, 11 %. No. 6. Sodium antimonate, 9 %. No. 5. Sodium antimonate, 7 %. No. 15*A*. Feldspar calcined, 9 %. No. 16*A*. Zinc aluminate calcined, 9 %. No. 8. Zinc aluminate calcined, 7 %. No. 16*B*. Zinc aluminate, 9 %. No. 16*D*. Zinc aluminate, 9 %.

The data on enameled cast-iron units are more limited. Over-all coefficients of heat transfer are given ranging from 1088 to 1464.

The thickness of the enamel coating rather than the thickness of the metal, seems to be the determining factor in the over-all coefficient.

THERMAL EMISSIVITY OF WHITE VITREOUS ENAMELED SURFACES

Very nearly the same as that of white-lead paint (4).

REFLECTIVITY OF SHEET STEEL ENAMELS

A typical white tin oxide enamel for sheet steel has an average reflectivity of 69%, relative to magnesium carbonate (7).

The same frit with other opacifying agents replacing tin oxide has reflectivities varying between 48 and 66% as shown in Figs. 2 and 3 (7).

See (27) for the effect of fineness of grinding on the opacity of enamels.

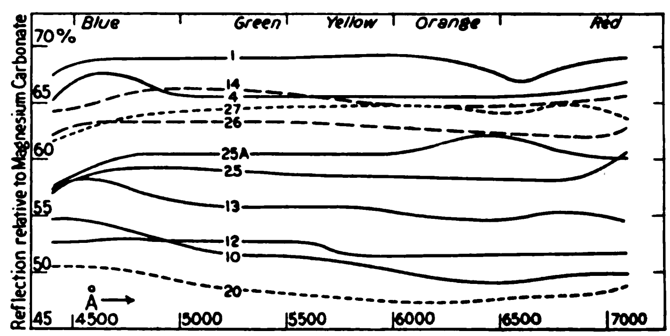

FIG. 3.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 4. Zirconium oxide, 7 %. No. 14. Zirconium oxide, 9 %. No. 10. Zirconium product, 7 %. No. 13. Commercial substitute, 7 %. No. 26. Zirconium silicate B, 9 %. No. 25. Zirconium silicate B, 7 %. No. 25*A*. Zirconium silicate B calcined, 7 %. No. 12. Zirconium silicate A, 7 %. No. 20. Zirconium silicate A, 11 %. No. 27. Zirconium silicate B, 11 %.

EXPANSION OF ENAMELS OF VARIOUS COMPOSITIONS (18)

Percentage composition of enamels

Type of enamel	SiO_2	B_2O_3	Cryolite		CaF_2	CoO	MnO	Al_2O_3	CaO	K_2O	Na_2O	$\frac{10^6\,dV}{V\,dt}$	
			AlF_3	NaF								Obs.	Calc.
Ground coat	51.00	15.79			5.44	0.25	0.71	7.86	1.51	2.60	14.84	28.8	27.6
	64.86	9.46			3.67	0.21	0.51	6.45	1.01	1.71	12.12	24.5	23.7
	54.69	12.47			4.68	0.31	0.45	8.83	1.26	2.54	14.77	28.9	27.9
Cover	55.91	6.96	3.95	6.03	1.73			10.30	0.54	1.73	12.85	32.7	32.1
	51.00	6.80	6.29	9.62				8.85	1.77	2.28	13.39	35.8	36.1
	51.40	8.31	3.87	5.77	2.14			11.58	1.30	0.97	14.66	34.6	33.8
	48.08	8.98	6.38	9.75				9.36	0.54	1.67	15.24	37.2	37.5
Cover, with various oxides							SnO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	31.8	31.8
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	30.9	31.6
							TiO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	32.7	32.2
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	31.1	32.4
							ZrO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	31.2	31.8
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	30.1	31.6
			As_2O_3	PbO	ZnO								
Dry process	33.92	5.01	5.23	44.61	3.34			0.22	0.41	0.75	6.51	30.1	30.7

ACID RESISTANCE OF VITREOUS ENAMELS

See (20, 16, 21, 5, 23, 14, 11, 29) for sheet steel enamels and (25) for cast iron enamels.

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STRUCTURAL CEMENTS, LIMES AND PLASTERS

P. H. Bates and W. E. Emley

HYDRAULIC CEMENTS

P. H. Bates

Hydraulic cements have the property of hardening under water and are usually made by burning argillaceous limestones or mixtures of argillaceous and calcareous materials. They include: portland, rosendale, natural, grappier, Eisenportland, Erzportland, Hochofen, trass, tufa, pozzuolana, etc., and hydraulic limes.

The definition and classification of cements is largely a matter of usage, which varies from nation to nation. In the U. S. there is a well-recognized standard for portland cement alone (A. S. T. M., C9–21).

A very infrequently used standard for natural cement differentiates this from portland cement only by its not requiring grinding before calcination, and giving different numerical values for the other properties (A. S. T. M., C10–09).

Rosendale, grappier, and hydraulic limes are natural cements in that the raw material is not ground before calcination. The other classes of cement mentioned above are mixtures of portland cement with various amounts of different slags of natural or of artificial origin. Their use is not very extensive and in general is confined to a few countries.

In France one standard covers the several varieties of hydraulic limes and cements (3).

"Hydraulic limes and cements will be called quick-, medium-, slow-, or extremely slow-setting according as their time of initial set is less than 5 min, 5 to 30 min, 30 min to 6 hr or more than 6 hr respectively.

"Until the time when compression test results can be generalized, the classification by strength shall be made as follows according to minimum strength in tension at 7 and 28 days."

Designation (package to show this designation)	Minimum tensile strength			
	kg cm^{-2}		lb. in.$^{-2}$	
	7 da	28 da	7 da	28 da
1/3 kg	1	3	14.2	42.6
3/5 kg	3	5	42.6	71.0
6/10 kg	6	10	85.0	142.0
10/15 kg	10	15	142.0	213.0
15/20 kg	15	20	213.0	284.0
20/25 kg	20	25	284.0	355.0

The chemical composition of all cements, even of the same class, varies widely. The following table, taken from the file of the U. S. Bureau of Standards, gives the composition of some portland cements of the U. S., wt. %:

SiO_2	22.25	25.02	20.75	22.66	20.37	23.40	19.03	19.82	20.80
Al_2O_3	6.63	6.08	7.79	5.58	3.64	6.97	8.75	7.62	6.94
Fe_2O_3	2.26	.49	2.40	4.51	8.97	2.68	4.75	2.10	3.84
CaO	63.84	62.89	60.48	62.22	61.42	60.87	62.81	62.04	64.12
MgO	2.41	1.11	3.28	.62	.82	1.13	1.33	3.90	1.02
SO_3	1.07	1.75	1.76	1.05	1.19	1.41	1.37	1.43	1.30
Na_2O	.21		.16	.17	1.54		.07	.24	
K_2O	.32		.80	.19	.24		.16	.26	
Ig. loss	1.14	2.03	2.76	2.86	2.07	2.78	1.56	2.72	1.26

In the following table are given the analyses of some other cements:

	Natural cements(10)			Hydraulic lime (3)	Erzportland(10)	Slag (CaS, 2.7 %) (10)	White (10)
SiO_2	20.85	24.07	23.81	22.89	20.37	30.19	22.66
Al_2O_3	6.04	11.69	8.01	2.15	3.64	11.08	8.61
Fe_2O_3	1.40	.35	4.18		8.97	1.64	.55
CaO	34.83	47.08	32.00	64.85	61.42	46.16	62.46
MgO	22.25	1.51	18.45	1.47	.82	2.17	1.10
Na_2O	.14	.25	.26		1.54	.29	.40
K_2O	1.60	.91	.44		.24	.64	.53
SO_3	2.11	.10	2.53	.61	1.19	1.10	1.64
Ig. loss	11.12	1.79	8.26	8.03	2.07	4.00	2.06

PORTLAND CEMENT

P. H. Bates

In view of the relatively very small amounts of cements used other than portland, and especially in view of the lack of any critical data on these other types of cements, this section will deal only with portland cements and products made therefrom.

Portland cement is a heterogeneous mixture of several compounds of silica, alumina and lime (being mostly $3CaO.SiO_2$,

$2CaO.SiO_2$, $3CaO.Al_2O_3$, glass and uncombined lime), produced by heating to incipient fusion finely ground mixtures of limestone, marl, or other calcareous compounds with certain argillaceous materials as clay, shale, slag, etc. The cement contains, in addition to the above, compounds or solid solutions of iron, magnesium, sodium, potassium, titanium, etc. The compounds present do not occur in fixed or definite quantities and as a consequence the properties of portland cement vary widely. Furthermore, as it is not stable towards water, moisture, or carbon dioxide in the presence of moisture, its properties are constantly changing (2).

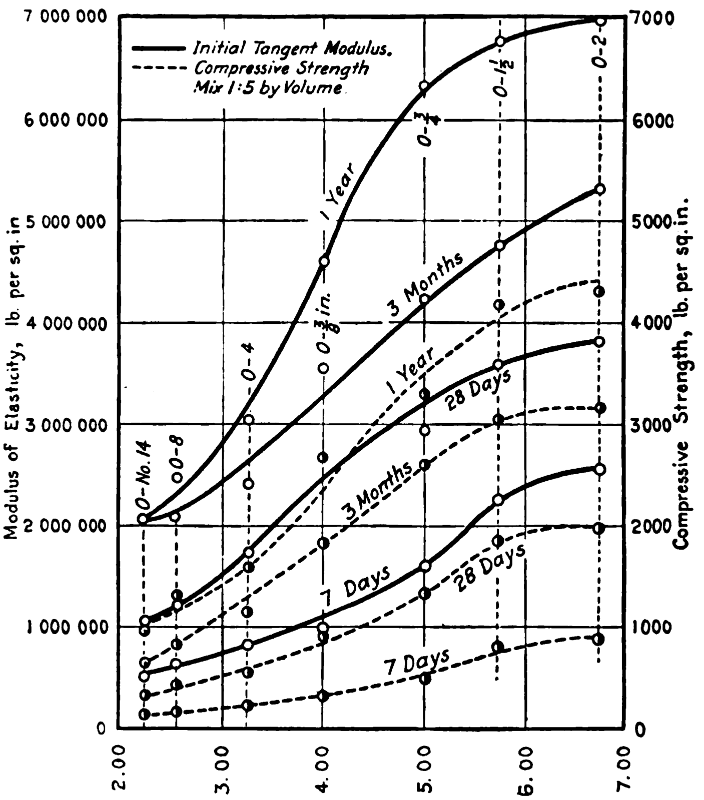

FIG. 1.—Effect of size of aggregate on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

On mixing portland cement with water certain hydration reactions take place. The character and degree of these reactions depend upon the amount of water used and the presence of dissolved salts. The character and the degree of the reaction determine also the physical properties of the resulting material.

In view of the lack of the use of cement in the neat form (cement and water without the presence of any aggregate, either fine or coarse) no data will be presented referring to the properties when so used. All data will refer to concrete—large particles bonded with cement, or mortar—fine particles, all passing the 3/8 inch sieve, bonded with cement.

Strength of Concrete

The following equations have been suggested for calculating the compressive strength (Def. 4). Feret (22) states that if values of the expression

$$\left(\frac{V_c}{1 - V_s - V_A}\right)^2$$

[where V_c = absolute volume of cement in unit volume of mortar,

V_s = abs. vol. of sand in unit vol. of mortar,

and V_A = abs. vol. of large aggregate in unit vol. of mortar] be graphed against the compressive strength (Def. 4) of any concrete made of any aggregate of the same consistency, aged under the same condition and for the same period, the points so obtained will lie close to a straight line passing through the origin.

According to Abrams (1) the compressive strength, S, is expressed by the equation $S = A/B^x$

where x = the $\frac{\text{water}}{\text{cement}}$ vol. ratio in the mixture, and A and B are constants depending upon the quality of cement, age of concrete, curing conditions, etc.

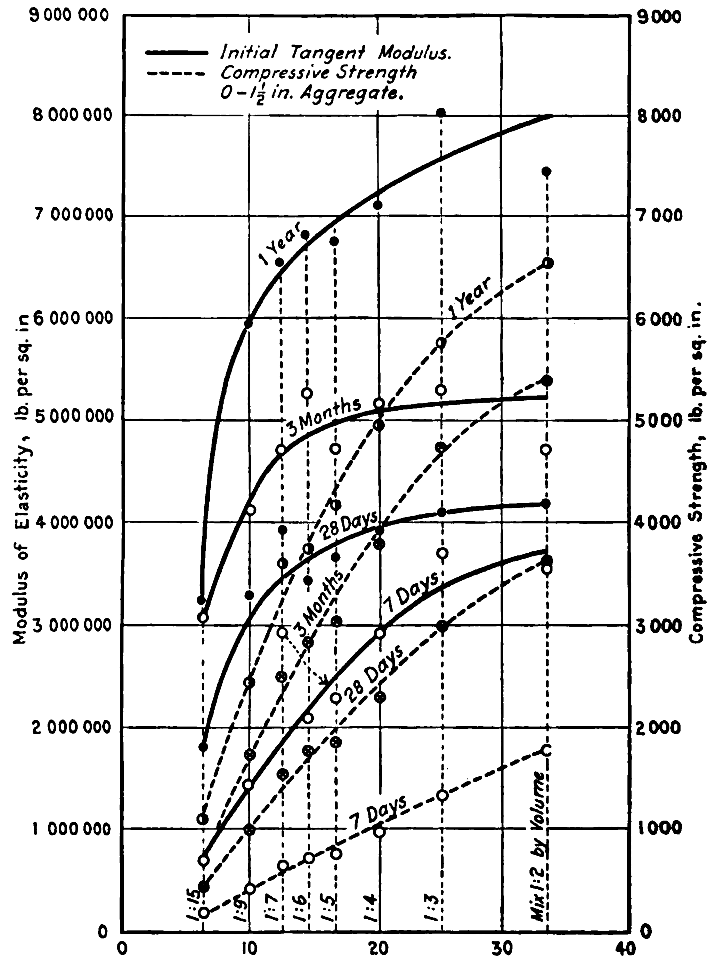

FIG. 2.—Effect of amount of cement on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate; graded 0-1½ in. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

Talbot (40) finds $S = 32\ 000\left(\frac{C}{V + C}\right)^{2.5}$ lb./in.^{2},

where C = vol. of cement in unit vol. mixture

and V = voids (air and water) in unit vol. mixture, when the "basic water" content is used. The "basic water" content is the amount of water per unit volume of the mortar that gives the minimum voids. The relation between strength and relative water content is not a straight line function. The strength of the concrete having a water content of 1.5 times that of the basic content would be reduced about one-third.

Modulus of Elasticity

Walker (42) gives $E = CS^m$
where E = modulus of elasticity,
C and m = constants depending upon the conditions of test,
and S = the compressive strength.

"Four different measures of modulus of elasticity of concrete are in more or less common use, as follows:
E_i = the initial tangent modulus;
E_t = tangent modulus at some load;
E_s = secant modulus at some load;
E_d = load modulus between two loads.

The initial tangent modulus for usual concrete mixtures may be represented by the equation $E_i = 33\ 000\ S^{5/8}$. For the tangent modulus at 25% of the compressive strength the equation becomes $E_t = 66\ 000\ S^{1/2}$."

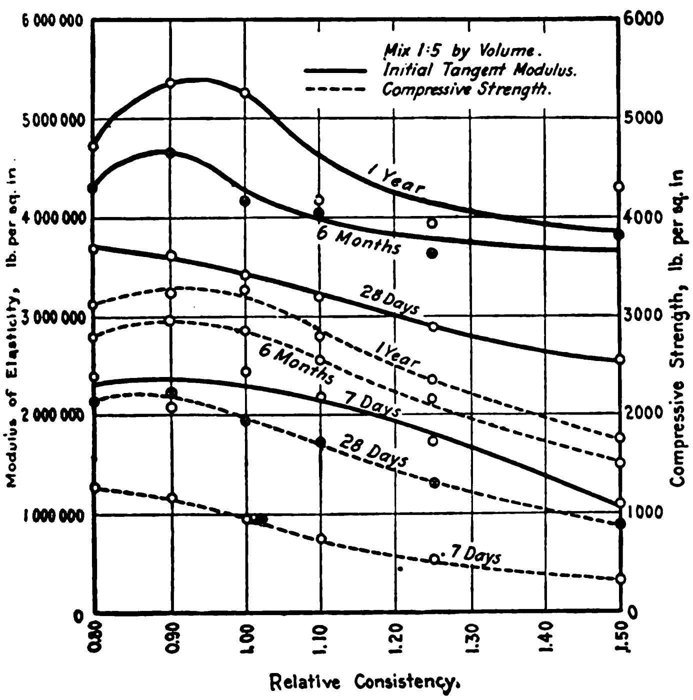

FIG. 3.—Effect of consistency of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Each value is the average of 15 tests from 3 sizes of sand and pebble aggregate.

Figures 1–4 illustrate the effect of the several variables mentioned above on the initial tangent modulus. In these graphs certain of the terms used have the same significance as indicated in the tables under "Strengths."

Poisson's Ratio (Def. 9)

Recorded values range from 0.08 to 0.18 (27, 39, 50).

Bulk Density

Varies from 0.68 to 0.90, according to grading and size of particles and is not affected by aging or slight changes in mixing temperature.

Thermal Expansion

Norton (34) found the following values for a "1:2:5 stone concrete." The concrete was permanently deformed by the heat treatment and did not return to its original length. The length on cooling was 75% of the maximum length obtained during heating.

Temperature range	$\frac{10^6 \Delta l}{l\ \Delta t}$
72°– 360°F	4.5 to 6.0
72°– 750°F	5.0 to 6.0
72°–1190°F	4.0 to 5.0
72°–1600°F	3.5 to 4.2

SPECIFIC HEAT (34)

Temperature range	g-cal g^{-1} deg.$^{-1}$C		
	1:2:5 stone	1:2:4 stone	1:2:4 cinder
72°– 312°F	0.156	0.154	
72°– 372°F	.192	.190	0.180
72°–1172°F	.201	.210	.206
72°–1472°F	.219	.214	.218

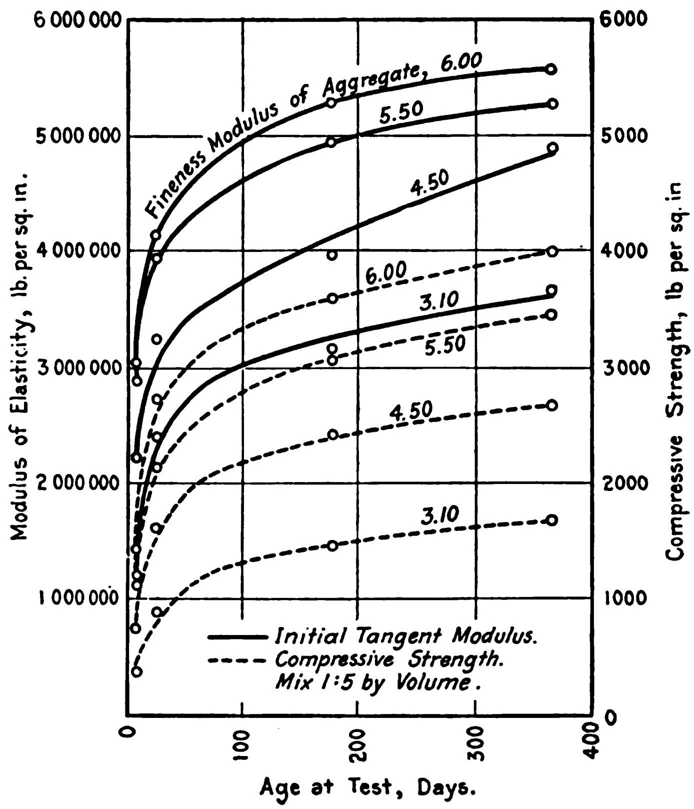

FIG. 4.—Effect of age of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Mix 1:5 by volume. Each value is the average of 30 to 35 tests from 6 or 7 consistencies.

Thermal Conductivity

1 g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ = 1.24 BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$

Upper temp., °C	Norton (34) Mix	k g-cal unit
35	stone 1-2-5*	0.00216
50	stone 1-2-4*	0.00113
50	cinder 1-2-4	0.00081
200	stone 1-2-4	0.0021
400	stone 1-2-4	0.0022
500	stone 1-2-4	0.0023
1000	stone 1-2-4	0.0027
1100	stone 1-2-4	0.0029

* Not tamped.

Mixture by volumes: Cement: aggregate	Mixture by volumes: Cement: sand: gravel	50°C to 100°C 120°F to 212°F	100°C to 200°C 212°F to 390°F	200°C to 300°C 390°F to 570°F
		g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$		
		k	k	k
"Neat"		0.00140	0.00163	0.00140
1-2	1-1.2-1.1	0.00326	0.00344	0.00318
1-3	1-1.9-1.7	0.00335	0.00379	0.00318
1-4	1-2.4-2.3	0.00413	0.00352	0.00328
1-5	1-3.1-3.0	0.00327	0.00323	0.00334
1-7	1-4.3-4.0	0.00400	0.00384	Carman and
1-9	1-5.6-5.1	0.00574	0.00352	Nelson (11)

Variation with Relative Water Content

Mixture	Relative water content, %	k 50°C to 100°C	k 100°C to 200°C	k 200°C to 300°C
1:2	100	0.00365	0.00322	0.00320
	110	0.00300	0.00332	0.00310
	120		0.00317	
1:3	100	0.00347	0.00365	0.00340
	110	0.00343	0.00391	
	120	0.00353	0.00345	0.00310
1:4	100		0.00357	
	110	0.00415	0.00373	0.00322
	120	0.00410	0.00316	
1:5	100		0.00353	
	110	0.00381	0.00380	0.00380
	120	0.00273	0.00305	0.00270
1:7	110	0.00402	0.00387	
	120		0.00300	
1:9	110	0.00573	0.00359	Carman and
	120		0.00273	Nelson (11)

Effect of Age (11)

Mixture	Relative water content %	Age days	k	Mixture	Relative water content %	Age days	k
1:2	110	28	0.00335	1:5	120	28	0.00330
		120	331			120	297
1:3	110	28	398	1:7	110	28	380
		120	365			120	380
1:4	110	28	376	1:9	110	28	340
		120	337			120	387

For additional data, *see* p. 122.

Thermal Diffusivity (11)

Diffusivity of Concrete, 100°–200°C

Relative water content, 110%

Mixture	Density g cm^{-3}	k	Specific heat cal g^{-1} °C^{-1}	Diffusivity cm^2 sec^{-1}
"Neat"	1.83	0.00147	0.278	0.00289
1-2	2.26	0.00344	0.216	0.00705
1-3	2.28	0.00379	0.218	0.00762
1-4	2.29	0.00352	0.218	0.00705
1-5	2.29	0.00323	0.217	0.00650
1-7	2.23	0.00384	0.227	0.00758
1-9	2.16	0.00352	0.223	0.00732

Setting Time

In the U. S., the standards of the Govt. and Amer. Eng. Stands. Com. require an initial set in not less than 1 hour, and a final set within 10 hours, as determined by a purely empirical test. In other countries cements may be made to meet various specification requirements as to setting (*cf.* p. 117). No method of measuring the set of mortars or concretes has been developed.

Time Rate of Change of Volume

These data have been obtained by linear measurements alone, and are as usual faulty, owing to lack of data that would accurately delimit the concrete under investigation. The change is among other variables a function of the size of specimen, amount of water used, and the humidity of the surrounding atmosphere. The values given indicate a contraction ranging from 0.018 to 0.08% for "reinforced concrete" (33).

Resistance to Weathering and Chemical Action

Mortars and concretes are attacked by acid. If dense and carbonated on the exterior they offer great resistance to weather and other chemical agents.

Tests of Portland Cement

Used in obtaining the data given in Tables 2, 3, 4, and 5.

The cement used in all tests consisted of a mixture of equal parts of four brands purchased in Chicago and gave satisfactory soundness tests (over boiling water).

Tests were made in accordance with the *Standard Specifications and Tests for Portland Cement*, A. S. T. M.

Miscellaneous tests

Fineness. Residue on No. 200 Tyler Sieve %	Normal consistency wt. %	Time of setting: Vicat needle, Initial hr	min	Vicat needle, Final hr	min	Gillmore needle, Initial hr	min	Gillmore needle, Final hr	min
18.8	24.0	3	40	8	20	5	45	9	40
17.6	23.0	3	45	8	00	6	30	8	30

Mortar strength tests

1:3 Standard Sand Mortar.

Mixing water %	Tensile strength (Def. 4) of briquets, lb./in.^{2} 7 da	28 da	3 mo	6 mo	1 yr	Compressive strength (Def. 4) 2 × 4 in. cylinders, lb./in.^{2} 7 da	28 da	3 mo	6 mo	1 yr
10.5	235	365	425	380	405	1670	2570	3520	4250	3840
10.3	280	430	410	385	355	1720	2870	3710	4150	4370

Table 2.—Effect of Curing Condition of Concrete

Mix, 1:4 by volume. Relative consistency of concrete, 1.10; water-ratio, 0.82. Age at test, 28 days.

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to 1½ in. Each value is the average of 5 tests made on different days.

Ref. No.*	Days storage: Damp burlap	Days storage: Dry air	Modulus of rupture of beams, lb./in.^{2}	Compressive strength of 6 × 12 in. cylinders, lb./in.^{2}	Modulus of rupture % compression
7, 8	28	0	550†	2580†	21.3
42	26	2	510	2630	19.4
43	21	7	450	2850	15.8
44	14	14	485	2920	16.6
45	7	21	470	3020	15.6
46	4	24	410	2330	17.6
47	0	28	370	2340	15.8
			Average 465	2670	17.5

* See Table 1 for Ref. Nos.

† Average of 25 beam tests and 115 cylinder tests.

Table 1.—Sieve Analysis and Unit Weight of Aggregates

Used in obtaining the data given in Tables 2, 3, 4, and 5.

Square mesh wire cloth sieves, Tyler Series (*v.* p. 329), were used in making sieve analyses. Each sieve has a clear opening twice the width of the preceding one.

Ref. No.	Aggregate		Sieve analysis									Fineness modulus of aggregate*	Unit weight, lb./ft.³
	Kind	Size / No.	Wt. % retained on each sieve										
			100	50	30	16	8	4	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$		
36		0–No. 16	97	78	20	0						1.95	108
37	Janesville sand	0–No. 8	98	80	28	11	0					2.17	111
38		0–No. 4	98	82	35	19	9	2	0			2.45	113
39		0–0.375 in.	99	90	63	54	49	45	0			4.00	123
40		0–0.75 in.	99	93	75	69	64	61	39	0		5.00	128
1–28, 41		0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
29		0–1.5 in.	98	84	43	30	20	14	8	3	0	3.00	118
30	Janesville sand and Elgin pebbles	0–1.5 in.	99	88	57	46	41	35	25	9	0	4.00	127
31		0–1.5 in.	99	90	64	56	51	46	33	11	0	4.50	131
32		0–1.5 in.	99	92	71	65	61	57	41	14	0	5.00	132
33		0–1.5 in.	99	93	75	70	66	62	45	15	0	5.25	133
34		0–1.5 in.	100	96	86	83	80	78	58	19	0	6.00	127
35		0–1.5 in.	100	97	89	86	85	84	63	21	0	6.25	124
42–53, 59–64	Janesville sand and Elgin pebbles	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
54	Janesville sand and crushed slag	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	118
55	Janesville sand and crushed limestone	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	129
56	Janesville sand and crushed granite	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	121
57	Washed Elgin sand and Elgin pebbles	0–1.5 in.	99	95	86	80	72	67	49	17	0	5.65	127
58	Unwashed Elgin sand and Elgin pebbles	0–1.5 in.	100	98	91	86	81	73	50	18	0	5.97	130

* Sum of per cents in sieve analysis, divided by 100.

Table 3.—Effect of Quantity of Cement and Mixing Water

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to 1½ in. Fineness modulus, 5.65. Age at test, 28 da. Specimens tested damp. Each value for modulus of rupture is the average of 10 tests, and for compressive strength 20 tests, made on 10 different days.

Ref. No.	Mix by volume	Cement vol. % of concrete	Relative consistency	Water-ratio of concrete	Modulus of rupture of beams, lb./in.² (7 in. deep, 10 in. wide, 38 in. long)			Compressive strength of 6 × 12 in. cylinders, lb./in.²	Modulus of rupture, % compression
					Bottom*	Top*	Aver.		
				Effect of quantity of cement					
1, 2	1:6	16.4	1.10	1.03	430	420	425	1820	23.4
3, 4	1:5	19.0	1.10	0.92	500	490	495	2140	23.1
5, 6	1:4.5	20.7	1.10	0.87	480	510	495	2130	23.2
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
9, 10	1:3.5	25.4	1.10	0.76	590	540	565	2980	19.0
11, 12	1:3	28.7	1.10	0.71	600	590	595	3480	17.1
13, 14	1:2.5	33.0	1.10	0.64	590	590	590	4110	14.3
15, 16	1:2	38.7	1.10	0.59	660	620	640	4390	14.6
				Average	550	540	545	2950	19.5
				Effect of quantity of mixing water					
17, 18	1:4	23.8	0.90	0.68	590	560	575	3760	15.3
19, 20	1:4	23.5	0.95	0.72	580	600	590	3280	18.0
21, 22	1:4	23.4	1.00	0.75	580	560	570	3100	18.4
23, 24	1:4	23.2	1.05	0.78	570	550	560	2720	20.6
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
25, 26	1:4	22.5	1.25	0.92	460	540	500	1920	26.0
27, 28	1:4	22.3	1.50	1.08	400	500	450	1300	34.6
				Average	535	550	540	2660	22.0

* Part of concrete beam (as molded) which was exposed to tensile stress during loading.

† Average of 25 beam tests and 115 cylinder tests.

Table 4.—Effect of Size and Grading of Aggregate

Aggregates: sand from Janesville, Wis., and pebbles from Elgin, Ill. Aggregates of different size were obtained by separating sand and pebbles into various sizes and recombining as shown by sieve analyses in Table 2. Different gradings of aggregates were produced by mixing sand (0 to No. 4) and pebbles (No. 4 to 1½ in.) in different proportions.

Mix, 1:5 volume. Relative consistency, 1.10. Specimens tested damp. Each value is the average of 5 tests made on different days.

Ref. No.	Aggregate		Water-ratio of concrete	Modulus of rupture of beams, lb./in.^{2}				Compressive strength 6 × 12 in. cylinder, lb./in.^{2}				Modulus of rupture % compression			
	Size	Fineness Modulus		7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
			Effect of size of aggregate												
36	0–16	1.95	1.29	95	160	255	340	270	620	1190	1600	35.2	25.8	21.5	21.2
37	0–8	2.17	1.25	95	195	320	370	360	850	1470	1860	26.4	23.0	21.8	19.9
38	0–4	2.45	1.20	125	250	370	425	430	1010	1620	2100	29.4	24.8	22.8	20.2
39	0–0.375	4.00	0.98	290	455	595	640	1040	2110	2930	4490	27.9	21.6	20.3	14.3
40	0–0.75	5.00	0.87	365	560	730	775	1290	2650	3650	4890	28.3	21.2	20.0	15.9
41	0–1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
			Average...	230	360	510	570	800	1640	2410	3320	29.5	22.9	21.5	18.2
			Effect of grading of aggregate												
29	0–1.5	3.00	1.11	165	255	410	450	620	1290	1640	2330	26.6	19.8	25.0	19.3
30	0–1.5	4.00	0.98	230	390	505	570	950	2000	2550	3230	24.2	19.5	19.8	17.7
31	0–1.5	4.50	0.93	285	485	610	645	1090	2190	2750	3830	26.2	22.2	22.2	16.9
32	0–1.5	5.00	0.87	325	505	660	710	1160	2410	3580	4510	28.0	21.0	18.4	15.8
33	0–1.5	5.25	0.85	365	555	735	820	1320	2940	3810	5340	27.7	18.9	19.3	15.4
41	0–1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
34	0–1.5	6.00	0.78	405	600	735	825	1300	2250	3310	4400	31.2	26.7	22.2	18.8
35	0–1.5	6.25	0.77	385	590	730	865	1140	1990	2840	4080	33.8	29.6	25.7	21.2
			Average...	320	490	650	720	1120	2210	3010	4090	28.4	22.4	21.9	17.8

* Average of 25 beam tests and 115 cylinder tests.

Table 5.—Effect of Kind of Aggregate

Mix, 1:4 by volume. Relative consistency, 1.10; water-ratio, 0.82.

Aggregate: sand, 0 to No. 4; and coarse aggregate, No. 4 to 1½ in.; all of same grading. Specimens tested damp. Age at test, 28 days. Each value is the average of 5 tests made on different days.

Ref. No.	Kind of aggregate		Modulus of rupture of beams, lb./in.^{2}				Compressive strength 6 by 12 in. cylinder, lb./in.^{2}				Modulus of rupture % compression			
	Sand	Coarse	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
7, 8	Janesville........	Elgin pebbles.....	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
54	Janesville........	Slag.............	450	585	765	760	1240	2300	3150	4530	36.3	25.4	24.3	16.8
55	Janesville........	Limestone........	440	595	790	830	1320	2350	3280	3970	33.4	25.3	24.1	20.9
56	Janesville........	Granite..........	375	540	665	725	1010	1980	2960	3760	37.1	27.3	22.4	19.3
57	Elgin washed.....	Elgin pebbles.....	405	595			1490	2640			27.2	22.5		
58	Elgin unwashed...	Elgin pebbles.....	425	610			1340	2520			31.7	24.2		
		Average........	420	580	760	800	1300	2390	3240	4320	32.6	24.3	23.4	18.8

* Average of 25 beam tests and 115 cylinder tests.

GYPSUM

(Plaster-of-Paris)

W. E. Emley

Raw Materials and Calcination.—Commercial gypsum should contain ≮ 64.5% $CaSO_4.2H_2O$ (A. S. T. M., C22–23T; C23–22). On calcination below 163°C, $CaSO_4.2H_2O$ (gypsum) = $CaSO_4.\frac{1}{2}H_2O + 1\frac{1}{2}H_2O$. Gentle calcination above 163°C, $CaSO_4.\frac{1}{2}H_2O$ = $CaSO_4$ (soluble anhydrite) + $\frac{1}{2}H_2O$. At higher temperatures $CaSO_4$ (soluble anhydrite) = $CaSO_4$ (natural anhydrite (insol.)) ([29, 44]). For *dissociation pressures*, consult this item in the index of I. C. T. Commercial calcination and product *v.* ([8, 21, 38]).

Properties.—The properties of products made from calcined gypsum are dependent upon the nature of the calcined gypsum (purity, method of calcination, and fineness), upon the quantity of water used in placing it, and upon the kind and amount of other materials (accelerators, retarders, lime, clay, sand) added to it. These facts must be constantly borne in mind when interpreting the figures given below.

Setting Time.—A normal figure is 6 min for no impression by Vicat needle ([24]) (A. S. T. M., C26–33). Doubling the amount of water will give 29 min ([24]). Fine grinding after calcination may lower to 3 min ([49]). The setting reaction is not complete when the Vicat needle indicates that the material is set. Evolution of heat continues and the temp. continues to rise for many min ([18]). If the calcined gypsum is of such a nature that a max. temp. rise of 14°C is attained in 53 min this time can be decreased to 21 min (by 2% sodium chloride) or increased to more than 240 min (by 2% calcium acetate) ([43]).

The commercial accelerator generally recommended is finely ground raw or set gypsum. The accelerating effect of this material is so powerful that especial care must be taken to clean all vessels

and tools before mixing a fresh batch of material. 0.5 to 0.6% of this material will decrease the time of set of gypsum plaster about 1 hr ([48]). Other soluble sulfates, such as are generally found in our water supplies, have similar effects.

Commercial retarder is a mixture made by cooking together soda, lime, and slaughter house refuse; 0.2% of this material will retard the time of set 2.5 to 3 hr ([43]). Carpenters' glue has a similar effect and is more readily obtainable.

Expansion on Setting.—Calcined gypsum will normally expand when it sets. Heavily retarded material may contract due to settling out of the solid. Calcined gypsum retarded to set in 2 hr and mixed with 35% water expanded 0.15% in length while setting. Increasing the water to 47% increased the expansion to 0.30%. Addition of sand seemed to have little effect.

After the gypsum has set and dried, wetting will cause expansion, drying, contraction. The magnitude of the movement is about 0.04% for the pure material. Addition of sand reduces this expansion, the reduction being proportional to the amount of sand, so that a specimen made of one part calcined gypsum to a little more than two parts of sand shows practically no movement, and leaner mixtures actually contract instead of expanding on being wetted ([35]).

Strength.—Calcined gypsum, if pure, properly calcined, of such fineness that it will all react, mixed with as little water as possible to bring it to a pouring consistency, molded in the form of a cylinder 2 in. diameter by 4 in. high, not retarded to such an extent that much water can evaporate prior to setting, and stored in a cool place until dry, will develop a compressive strength of at least 1000 lb./in.^{2} (A. S. T. M. C23-22); av. 1665, max. 2285 ([21]).

Naturally occurring impurities or added materials (except accelerators) will decrease the strength. The average figure for the compressive strength of a mixture of one part calcined gypsum to two parts sand by weight may be taken at 415 lb./in.^{2} ([21]); for a 1:3 mixture the figure is 335. Lime and clay reduce the strength at early ages, but this is gradually recovered ([36]). Portland cement reduces the strength in proportion to the cement added until the mixture reaches a minimum at 20% gypsum 80% cement, the strength of which is little more than half that of calcined gypsum ([35]).

Increased fineness up to 80% through a No. 100 U. S. Stand. sieve (*v.* p. 329), by making the calcined gypsum more reactive, causes increased strength. This size is 50% stronger than material only 40% of which passes a No. 100 sieve. Further increase in fineness is accompanied by a decrease in strength because more water is required to bring the mixture to a workable consistency ([45]).

The above figures are based on the max. consistency thickness which will allow pouring. Thicker consistencies will give greater strength, clear to the limit of workability of the mixture ([9]). Thinner consistencies will give lower strengths to zero, for calcined gypsum will not harden under water.

While there is a tendency for accelerators to increase the strength of calcined gypsum and for retarders to reduce it, the action of neither is marked unless retarder is present in sufficient amount to delay the set until the water required for setting has evaporated. Two per cent calcium acetate, for example, will retard calcined gypsum so far as to destroy completely its strength ([43]).

Castings made of calcined gypsum are strongest when completely dry. Moisture, or more particularly percolating water, seems to dissolve the bond between the crystals, resulting in permanent loss of strength or eventual disintegration. On account of the comparatively high dissociation pressure of gypsum at ordinary temperatures (100 mm Hg at 62°C) ([41]), it is dangerous to resort to artificial drying. The strength reaches very nearly its maximum as soon as the casting is dry, so that the age of a test specimen is of little importance (A. S. T. M. C26-23).

The ratio compressive strength/tensile strength = *ca.* 4.62 ([21]).

Thermal Conductivity and Fire Resistance.—([25]). (*See also* p. 315.)

Heat of Dehydration.—*See* I. C. T. Section on Thermochemistry.

Porosity, Solubility and Weather Resistance.—Calcined gypsum will not harden under water. When hardened in air and immersed in running water, castings made of calcined gypsum will eventually disintegrate. Calcined gypsum should not be used in situations where it will be exposed to the weather unless special precautions are taken.

These characteristics are usually attributed to the fact that gypsum is "quite soluble," but it is now believed that they are dependent more upon porosity than solubility.

The solubility of gypsum in pure water varies from 0.18% at 0°C to a maximum of 0.21% at 40°C, but it is much more soluble in water containing certain common salts ([23]). Taking the weight of set gypsum at 77 lb./ft.^{3} ([32]) and the specific gravity of the solid material at 2.35, the pores must occupy 47.5% of the total volume. (This figure may vary within wide limits, depending upon the fineness of the calcined gypsum and the quantity of mixing water used.) Owing to the crystalline nature of the material, these pores are comparatively large and afford passages for circulation of water, thereby rendering material assistance in the solution of the gypsum.

It has been found that if calcined gypsum is heavily retarded so that it can be trowelled frequently while setting, the dense surface thus produced is quite effective in improving the weather resistance of the finished product ([46]).

LIME MORTAR AND MASONRY

W. E. Emley

Commercial limes and mortars are made by mixing properly calcined limestone with water, or water and sand. Their properties depend on many variables, lack of control of which render most of the published quantitative data valueless. For the available qualitative information, reference should be made to the literature cited.

Raw Materials

Nature of Raw Materials, Commercial Definitions and Specifications ([12]).—(A. S. T. M. C51-22T; C5-22T).

Density.—*v.* p. 53.

Porosity.—Limestone usually less than 1 vol. % (*v.* p. 53).

Dissociation Pressure and Rate of Dissociation.—The dissociation pressure reaches 1 atm at 898°C for $CaCO_3$ and 756.5°C for $MgCO_3$. For further data, *v.* "Dissociation pressure" in the index of I. C. T. Commercial calcination is *ca.* 6 hr at *ca.* 1400°C ([6, 15]).

Other Properties.—*See* the pure materials in the various tables of I. C. T. *See also* p. 47.

Hydrated Lime and Lime Putty

Manufacture.—When CaO is properly mixed with an excess of water sufficient to keep the temp. below 100°C "lime putty" is obtained. With less excess, the resultant product is dry "hydrated lime." With still less water, the temperature may rise above 375°C and an "oxyhydrate" is obtained ([17, 26]).

"Plasticity."—([20, 25, 26, 28]).

Lime Mortars

Decrease in Volume on "Setting."—From 9% for non-plastic to 27% for plastic lime putty ([28]). This contraction is in practice reduced to *ca.* 5% by admixture of 80–90% of sand ([5, 40]).

Setting Time.—No agreement as to definition of term. The following laboratory test has been proposed ([37]):

Setting shall be assumed to be attained when an electrical resistance of 30 000 ohms is reached between two 5 mm brass plugs imbedded 8 mm in the plaster with their centers 10 cm apart.

Under this definition, neat lime putty will set in 40–50 hr, and this may be reduced 5–10 hr by admixture of sand (37).

Rate of Carbonation.—As ordinarily mixed and placed, lime mortar will carbonate from the surface inwards at *ca.* 1/8 in. per month (16). This is subject to change, within narrow limits, by variations of the factors enumerated above. A 2-in. cube exposed on 5 sides will carbonate completely in *ca.* 8 months; an 8-in. mortar joint exposed on one side will require more than 5 years.

Soundness.—(20, 31, 47).

Strength.—For purposes of intercomparison only, the following figures may be quoted as the strength of a mortar made of high calcium hydrate with three parts by weight of run-of-mine Ottawa sand and enough water to bring the mixture to "Standard" consistency (19) on the plunger viscometer, the mortar being molded in the form of 2-in. cubes for compression, the usual type of briquette for tension, and 12 × 1 × 1 in. bars for transverse and shear, and the specimens stored in the laboratory, with 5 sides exposed, for 90 days: Compressive, 403; Tensile, 69; Shearing, 82; Transverse, 146 lb./in.^{2}

Expansion after Setting.—No published data. Humidity and thermal coefficients at room temperature approximately equal to those of concrete. Thermal coefficient much greater at higher temperatures (9).

Strength of Masonry (7, 13).—Common brick masonry (1 to 4 pt. by vol. lime mortar) should withstand a compression of 125 lb./in.^{2} (14). *See also* p. 66.

Thermal Conductivity and Fire Resistance —(25).

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(For a key to the periodicals see end of volume)

(1) Abrams, *309*, No. **1**; 22. (2) *Ibid.*, No. **6**; 24. (3) Ancienne Soc. J. and A. Pavin de LaFarge, *Sales Circ.* (4) Anon, *66*, **23 II**: 432; 23. (5) Anon., *Nat. Lime Assoc., Bull.* No. **305A**. (6) Bleininger and Emley, *81*, **13**: 618; 11. (7) Bragg, *32*, No. **111**; 18. (8) Bur. Standards, *Circ. No.* **108**; 21. (9) *Ibid.*, No. **151**; 24.

(10) Bur. Standards, *O.* (11) Carman and Nelson, *86*, No. **122**: 29; 21. (12) Clarke, *156*, No. **695**: 557; 20. (13) Cleare, *Proc. Sand Lime Brick Assoc.*, **1920**: 57. (14) Dept. of Commerce, *Report of building code committee*, 1925. (15) Emley, *32*, No. **16**: 84; 13. (16) Emley, *81*, **16**: 117; 14. (17) Emley, *310*, **1914**: 254. (18) Emley, *81*, **19**: 573; 17. (19) Emley, *32*, No. **169**; 20.

(20) Emley and Berger, *38*, **6**: 1007; 23. (21) Emley and Faxon, *38*, **3**: 984; 20. (22) Feret, *311*, **6**, No. **3**: 63; 23. (23) Gale and Schaller, *156*, No. **580**: 302; 14. (24) Householder, *38*, **1**: 578; 18. (25) Hull, *32*, No. **130**; 19. (26) Hursh, *81*, **14**: 792; 12. (27) Johnson, *66*, **24 II**: 1024; 24. (28) Johnson, *O.* (29) Larsen, *66*, **23 I**: 236; 23.

(30) Lazell, *Hydrated Lime*, p. 39; 15. (31) Lazell, *310*, **1905**: 135. (32) Marani *in* Kidder-Nolan *Architects' Handbook*, 1918. (33) Matsumoto, *86*, No. **126**: 5; 21. (34) Norton, *122*, **35**: 1012; 13. (35) Porter, *66*, **23 I**: 244; 23. (36) Porter, *Rock Products*, **1924**: 47. (37) Stockett, *O.* (38) Stone, *30*, No. **155**; 17. (39) Talbot, *86*, No. **20**; 08.

(40) Talbot and Richart, *86*, No. **137**; 23. (41) van't Hoff, *7*, **45**: 257; 03. (42) Walker, *309*, No. **5**; 23. (43) Welch, *38*, **6**: 1197; 23. (44) Welch, *45*, **16**: 238; 24. (45) Welch and Emley, *38*, **4**: 301; 21. (46) Welch, *O.* (47) White, *310*, **1916**: 109. (48) Wilder, *Iowa Geol. Sur.*, **18**: 371; 18. (49) Winterbottom, *S. Australia Chem. Dept., Bull.* No. **7**; 17.

(50) Withey, *Univ. Wisconsin*, Bull. No. **466**; 11.

MAGNESIA CEMENTS AND CONCRETES

LEROY C. STEWART

BULK DENSITY (7)

Grams per cm^3: Stucco, 3.0 to 3.4. Flooring, 1.55 to 1.8. Special mixes with wood flour, cork dust, etc., 1.0 to 2.0.

ULTIMATE TENSILE STRENGTH (DEF. 4) AND MODULUS OF RUPTURE (DEF. 5) OF CEMENTS MADE WITH SPECIALLY CALCINED DOLOMITES

Wt. %: Calcined dolomite 31, ground flint 12.5, Ottawa sand 56.5. 1.179 sp. gr. $MgCl_2$ soln., kg/cm^2 (22).

Dolomite	Tensile strength			Modulus of rupture*		
	1 day	3 days	7 days	Not sprayed	Wet	Recovered
A			32.6	112.2	54.0	68.0
B	18.1	30.2	34.4	133.0	69.6	102.6

* Bars sprayed 24 hr at 14, 16 and 18 days' age. "Wet" bars broken at 19 days' age and "Recovered" at 21 days' age. "Not Sprayed" bars broken at 20 days' age.

ELASTIC PROPERTIES

Elastic limit (Def. 2), modulus of elasticity (Def. 10a) and ultimate compressive strength (Def. 4) of cement mortar and concrete.

1.23 sp. gr. $MgCl_2$ soln. used. Aged 80–85 days. Unit kg/cm^2 (1).

Magnesite-sand-rock by wt.	Elas. lim.	Mod. elas.	Compr. str.
1- 4-0	253	194 000	319
1- 6-0	150	192 000	240
1- 8-0	127	146 000	185
1-10-0	53-114	96 400	143
1- 2-4	234	269 000	359
1- 3-6	234	194 000	305

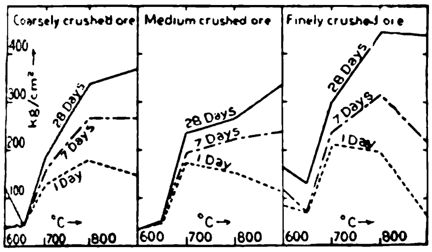

FIG. 1.—Ultimate compressive strength (Def. 4) of magnesium oxychloride flooring mixtures as affected by size and burning temperature of magnesite ore (3).

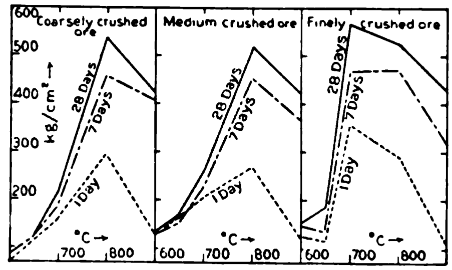

FIG. 2.—Ultimate compressive strength (Def. 4) of magnesium oxychloride mortar mixtures as affected by size and burning temperature of magnesite ore (3).

Graphs in Figs. 1 and 2 represent averages of three compositions, using $MgCl_2$ solution (sp. gr. 1.184) and Washington magnesite. Coarse ore passed 3.35 mm sieve, retained on 2.00 mm; medium passed 2.00 mm, retained on 0.585 mm; fine passed 0.249 mm opening.

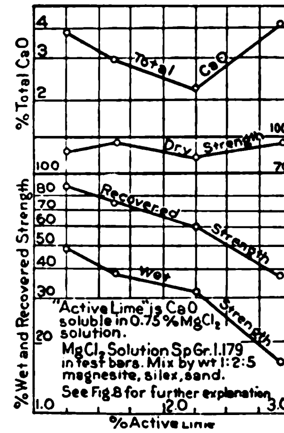

FIG. 9.—Effect of active lime in magnesite on magnesium oxychloride cement (21).

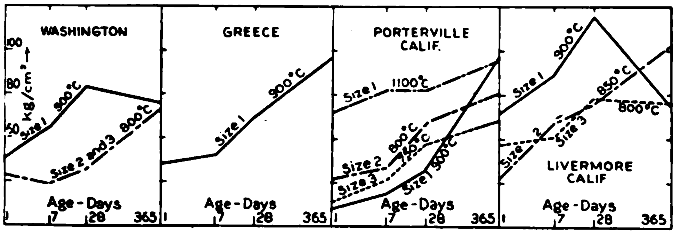

FIG. 3.—Modulus of rupture (Def. 5) of magnesium oxychloride flooring mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes of magnesite: 1, passing 2.54 cm, retained on 1.27 cm screen; 2, passing 1.27 cm, retained on 0.64 cm screen; 3, passing 0.64 cm, retained on 0.32 cm screen. Mix: 45 % MgO, 10 % wood flour, 5 % asbestos, 20 % silex, 5 % silocel, 5 % clay, 10 % pigment (all by weight); $MgCl_2$ soln., sp. gr. 1.179.

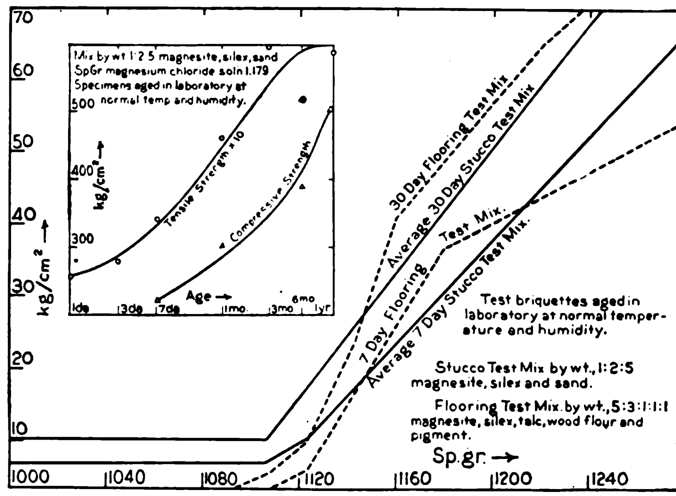

FIG. 5 (Insert).—Strength of magnesium oxychloride cements (7). Average for 12 commercial magnesites.

FIG. 6.—Effect of magnesium chloride solution strength on tensile strength of oxychloride cements (11).

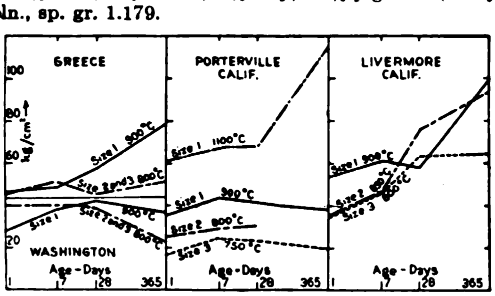

FIG. 4.—Modulus of rupture (Def. 5) of magnesium oxychloride stucco mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes as in Fig. 3. Mix: 10 % MgO, 20 % silex, 67 % mortar sand, 3 % asbestos (all by weight); $MgCl_2$ soln., sp. gr. 1.179.

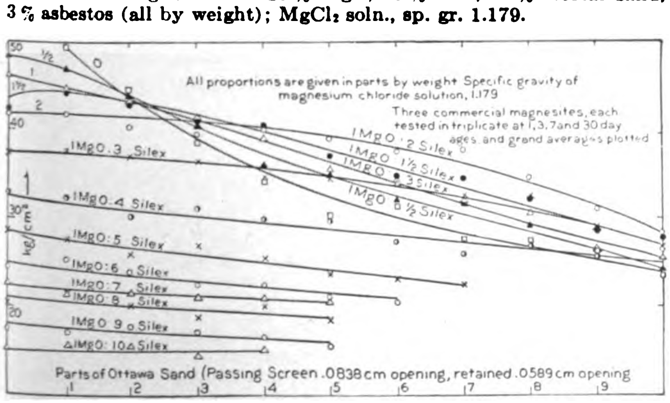

FIG. 7.—Tensile strength of oxychloride-silex-sand mixtures (8).

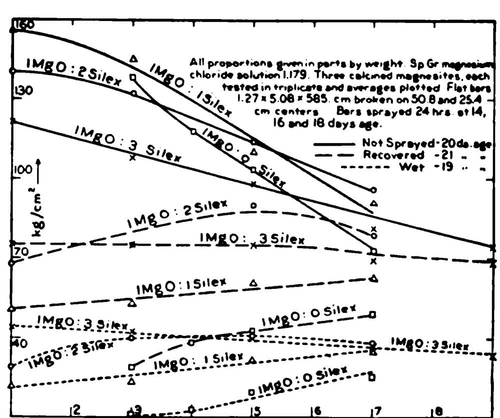

FIG. 8.—Water resistance of oxychloride-silex-sand mixtures. Modulus of rupture (10).

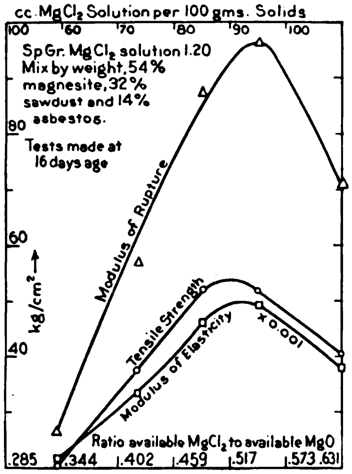

FIG. 10.—Effect of variation in amount of magnesium chloride solution on strength and elasticity of magnesium oxychloride flooring (19).

Modulus of elasticity $= Pl^3/4dbh^3$, where P = load applied at center, l = length of bar between supports, d = deflection of supports at center, b = width of bar and h = thickness of bar.

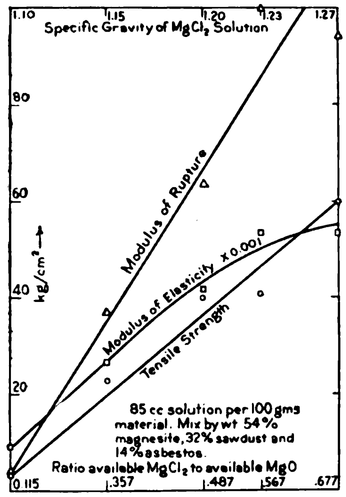

FIG. 11.—Effect of variation in density of magnesium chloride solution on strength and elasticity of magnesium oxychloride solution (19).

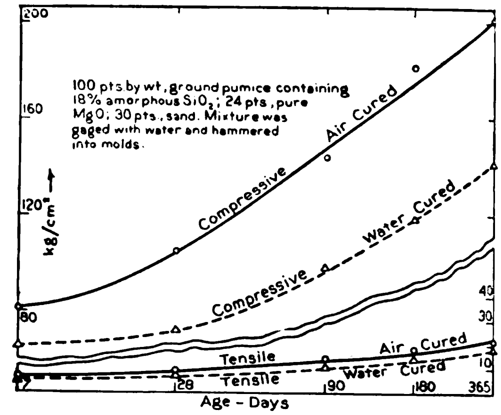

FIG. 15.—Tensile and compressive strengths of an hydraulic magnesian cement (24).

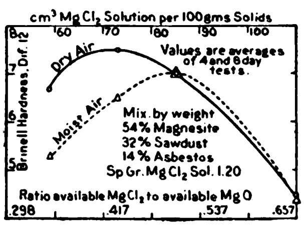

FIG. 12.—Effect of variation in amount of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

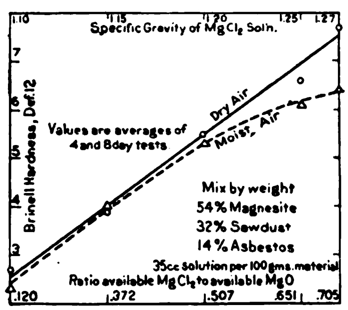

FIG. 13.—Effect of variation in density of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

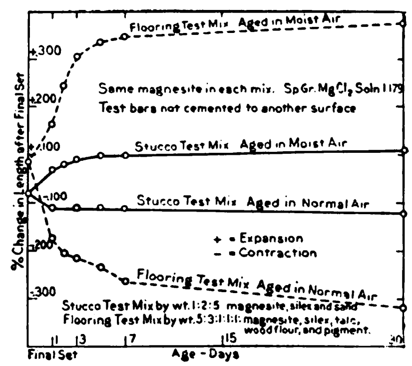

FIG. 16.—Volume change in magnesium oxychloride cements (7).

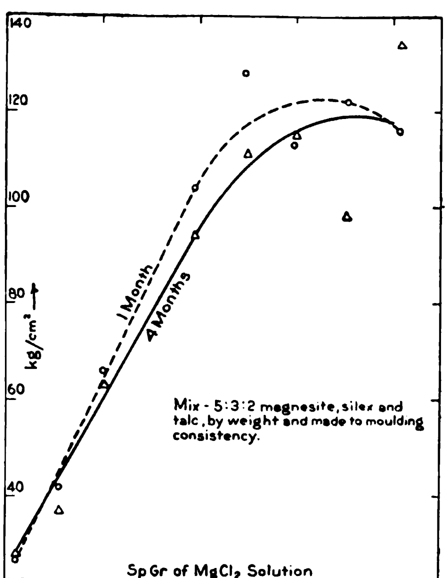

FIG. 14.—Tensile strength of high magnesite oxychloride mixtures as affected by density of magnesium chloride solution (7).

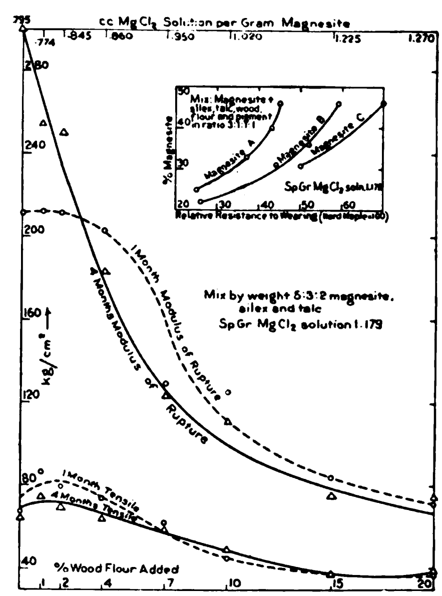

FIG. 17.—Effect of wood flour on strength of magnesium oxychloride cement mixture (7).

FIG. 18 (Insert).—Effect of % of magnesite on wearing resistance of magnesium oxychloride flooring (12).

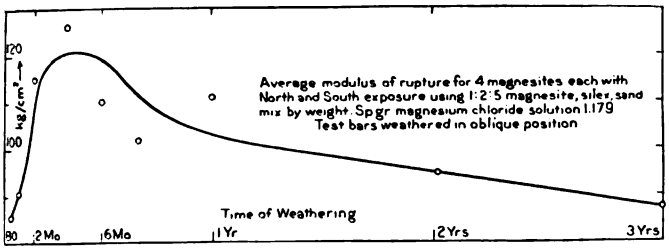

FIG. 19.—Permanency of magnesium oxychloride cement under exterior weathering (7).

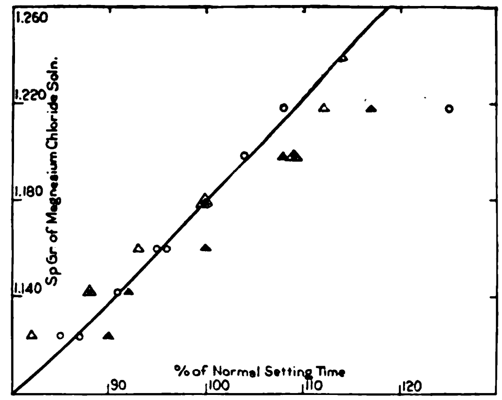

FIG. 23.—Effect of magnesium chloride solution strength on setting time of oxychloride cement (9).

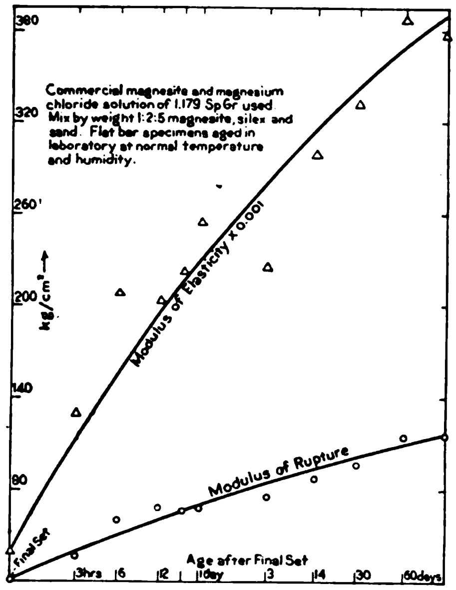

FIG. 20.—Transverse strength and elasticity of magnesium oxychloride cement at various ages (7).

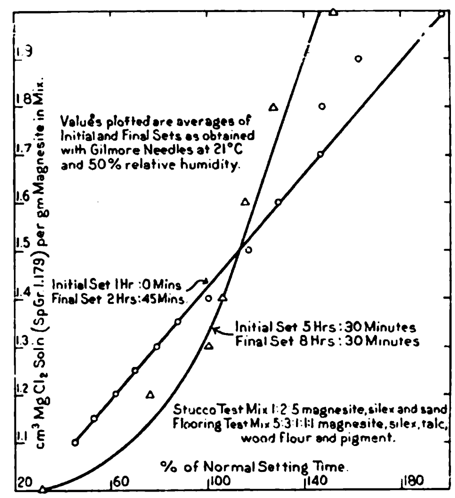

FIG. 24.—Effect of consistency on setting time of magnesium oxychloride cements (9).

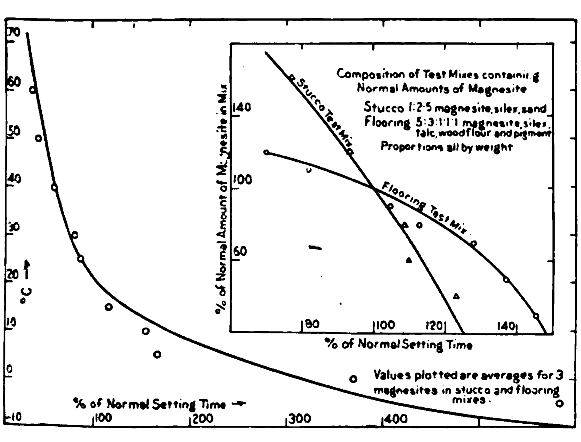

FIG. 21.—Effect of temperature on setting time of magnesium oxychloride cements (9).
FIG. 22 (Insert).—Effect of magnesite proportion on setting time of magnesium oxychloride cements (9).

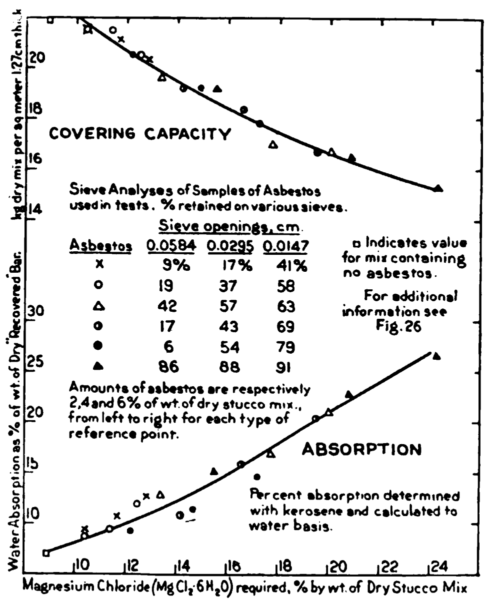

FIG. 25.—Effect of kind and amount of asbestos on covering capacity and absorption of magnesium oxychloride stucco (7).

Coefficient of Static Friction of Commercial Magnesium Oxychloride Flooring (7)

	Coefficient of friction
Flooring on flooring	0.35–0.50
Leather on flooring	0.45–0.70
Wood (parallel to grain) on flooring	0.25–0.50

WEARING RESISTANCE

Effect of fiber variation on wearing resistance of magnesium oxychloride flooring (12).

Wt. %: Magnesite 46, silex 27, talc 9, fiber 9, pigment 9; 1.179 sp. gr. $MgCl_2$ soln. Wearing resistance of hard maple taken as 100 (12).

Fiber	Asbestos			White pine		Hard maple		Oak		Calif. red-wood		Cork		Hard yellow pine sawdust
	Long fiber	Medium fiber	Short fiber	Sawdust	Flour	Sawdust	Flour	Sawdust	Flour	Sawdust	Flour	Granulated	Flour	
Wear. resist.	61	55	47	50	42	40	31	45	41	43	38	56	50	43

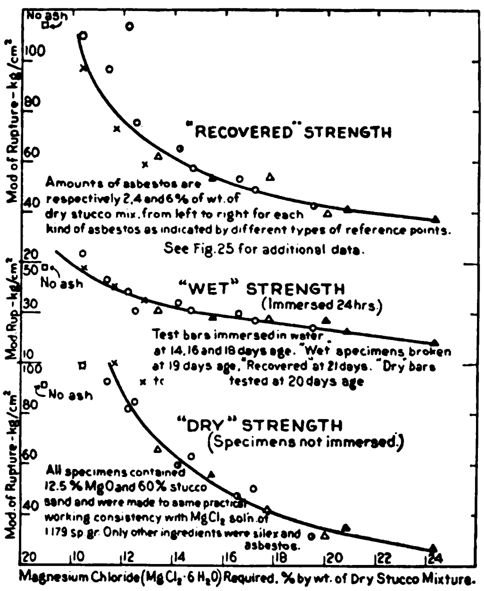

FIG. 26.—Effect of kind and amount of asbestos on water resistance of magnesium oxychloride stucco (7).

COEFFICIENT OF LINEAR THERMAL EXPANSION

Dry ingredients by weight	Sp. gr. $MgCl_2$ solution	$10^6 \frac{l}{l} \frac{}{\Delta t}$	Δt°C	Lit.
1 magnesite : 4 sand	1.23	12.60	13–93	(1)
1 magnesite : 6 sand	1.23	11.4	13–93	(1)
54 magnesite : 32 sawdust : 14 asbestos	1.20	22.7	Room	(19)
1 magnesite : 2 silex : 5 sand	1.179	15.1	4–51	(18)

SPECIFIC HEAT AND THERMAL CONDUCTIVITY OF CEMENT MORTARS (1)

By wt. mag.-sand	Sp. gr. $MgCl_2$ soln.	c_p, cal g°C	k, cal cm^{-2} sec^{-1}(°C cm^{-1})$^{-1}$
1–4	1.23	0.19	0.0042
1–6	1.23	0.20	0.0045

(*See also* p. 314.)

HEAT EVOLVED DURING MIXING AND SETTING OF MAGNESIUM OXYCHLORIDE CEMENTS (7)

150 to 250 g-cal per gram of commercially calcined magnesite.

ELECTRICAL RESISTANCE OF CEMENT MORTARS

1.23 sp. gr. $MgCl_2$ solution. R for various ages in megohm-cm (1)

Magnesite-sand by wt.	2 days	2 mo. dry	2 mo. wet
1–4	0.025	200	0.0012
1–6	0.032	138	0.001

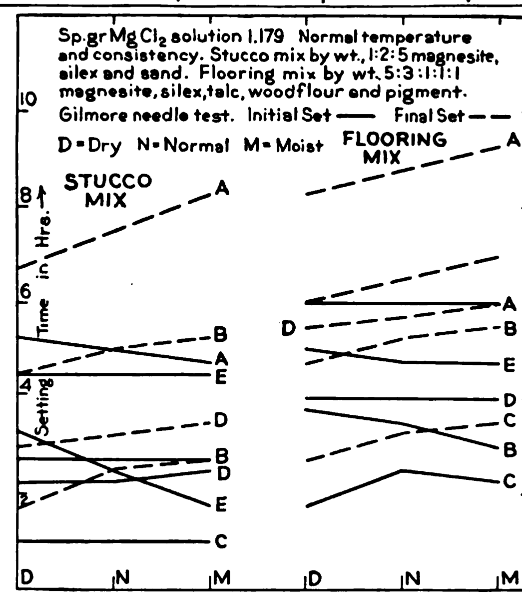

FIG. 27.—Effect of humidity on setting time of magnesium oxychloride cements (9).

SETTING TIME OF COMMERCIAL MAGNESITES IN VARIOUS MIXES (9)

Sp. gr. $MgCl_2$ soln. 1.179. Normal temperature, humidity and consistency. Stucco test mix by weight, 1:2:5 magnesite, silex and sand. Flooring test mix by weight, 5:3:1:1:1 magnesite, silex, talc, wood flour and pigment. Time of set determined with Gilmore needles.

For fourteen different samples of commercial magnesites, the initial set for neat mix varies from 0.5–6.25 hr, the final set from 1.5–16 hr; for stucco test mix, the initial set from 1–7.5 hr, final set, 2.75–11.5 hr; for flooring test mix, initial set, 1.5–8 hr, final set, 3–15 hr, depending on the nature of the magnesite.

Setting Time of Magnesium Oxychloride Cement Mixtures

Effect of source, size and burning temperature of magnesite ore (4). Flooring mix: Wt. %: MgO 45, wood flour 10, asbestos 5, silex 20, silocel 5, clay 5, pigment 10. Stucco mix: Wt. %: MgO 10, silex 20, mortar sand 67, asbestos 3. 1.179 sp. gr. $MgCl_2$ soln. Gilmore needles.

Magnesite		t°C	Flooring mix				Stucco mix			
			Initial		Final		Initial		Final	
Source	Size*		Hr	Min	Hr	Min	Hr	Min	Hr	Min
Washington	1	900	3	45	8+		2	05	6	55
Washington	2+3	800	1	20	3	50	2	00	3	40
Greece	1	900	1	15	3	00	1	25	3	15
Greece	2	800					0	50	2	25
Porterville, Calif.	1	1100	1	35	3	50	2	45	3	40
Porterville, Calif.	1	900	0	30	2	30	0	55	2	00
Porterville, Calif.	2	800	1	15	2	50	0	55	1	50
Porterville, Calif.	3	750	3	15	5	45	4	00	6	05
Livermore, Calif.	1	900	2	15	4	00	2	30	4	30
Livermore, Calif.	2	850	1	10	2	20	1	50	3	20
Livermore, Calif.	3	800	1	15	2	25	1	15	2	00

* Sizes of Magnesite: 1—passing 2.54 cm, retained on 1.27 cm screen; 2—passing 1.27 cm, retained on 0.64 cm screen; 3—passing 0.64 cm, retained on 0.32 cm screen.

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(For a key to the periodicals see end of volume)

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DENTAL CEMENTS

W. B. Holmes

1. TYPICAL CHEMICAL COMPOSITIONS, WEIGHT %

Zinc Oxide Cements

Powder		Liquids	
ZnO	70–100	Sp. gr.	1.55–1.85
Bi_2O_3	0–6	P_2O_5	33–50
MgO	0–9	H_2O	45–67
Fe_2O_3	0–2	Al_2O_3	4–6
*Al_2O_3	0–7	Na_2O	0–3
*SiO_2	0–8		
*PO_4	0–2		

Siliceous Cements

Powder		Liquids	
SiO_2	25–45	Sp. gr.	1.50–1.80
Al_2O_3	27–40	P_2O_5	35–45
CaO	4–13	H_2O	44–70
Na_2O	0–8	Al_2O_3	4–6
*BeO	0–16	ZnO	0–8
PO_4	4–24		
F	0–10		

Copper Cements

Powder		Liquids	
ZnO	0–90	Sp. gr.	1.50–1.70
CuO	0–90	P_2O_5	33–45
Cu_2O	0–30	H_2O	44–65
Cu_2I_2	0–5	Al_2O_3	4–6
Co_2O_3	0–8	ZnO	0–4
Fe_2O_3	0–20	FeO	0–4
$CuSiO_3$	0–1	NiO	0–1
$Cu_3(PO_4)_2$	0–5	CuO	0–1

*MgO.

2. CRUSHING STRENGTH([1])

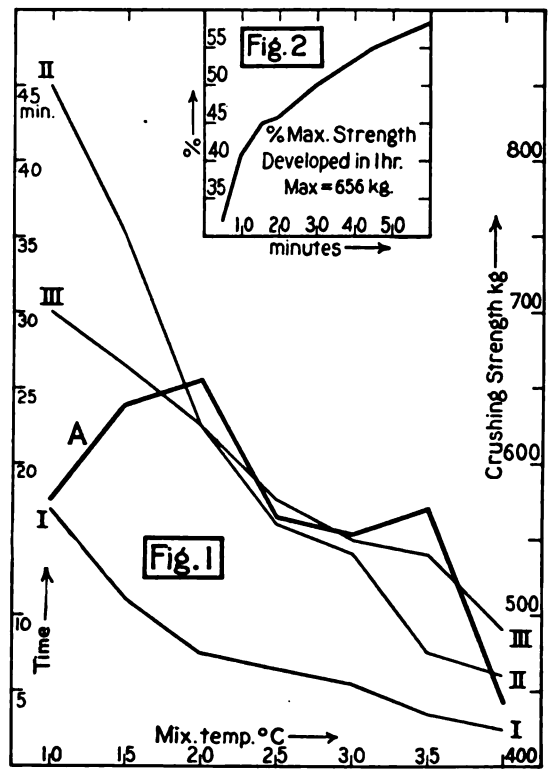
1. *Limits for Commercial Cements.*—Cement mixed at 20°C and then incubated at 37°C in oil. For the saliva tests the cylinders are incubated in oil for 15 min, then washed with petroleum ether and the incubation continued in saliva. Pressure applied to a cylinder (5 × 5 mm) at the rate of 453.6 kg/min.

Type and No. of samples tested \ Incubation:	(1) In oil for 15 min	1 day	7 days	28 days
	Crushing strength. Unit = 100 kg			
Sil. (7)	1.5–2.8	3.3–5.6	4.1–6.3	4.0–6.5
ZnO (18)	0.4–3.5	0.9–4.8	0.7–5.6	1.0–5.6
Cu (15)	0.5–2.9	0.5–4.4	0.4–5.4	0.7–5.4

Type and No. of samples tested \ Incubation:	(2) In saliva for 1 day	7 days	28 days
	Crushing strength. Unit = 100 kg		
Sil. (7)	1.0–5.6	1.1–5.9	1.2–6.6
ZnO (18)	0.9–4.4	1.1–4.9	1.0–4.4
Cu (15)	0.8–4.4	1.2–4.5	0.0–4.3

2. *Influence of Mixing Temperature.*—*See* Curve A, Fig. 1.

3. *Rate of Hardening of a "Synthetic Porcelain" Cement at 37°C as Measured by Its Crushing Strength.*—*See* Fig. 2, which gives the crushing strength in % of maximum strength, during the first hour.



3. SETTING TIME([1])

Time from mixing to failure of Gilmore needle to indent in 5 sec application. Seven siliceous cements, 5–12 min; 18 ZnO cements, 9–78 min; 15 Cu cements, 8–25 min; t = 20°C. For influence of mixing temperature *see* Fig. 1, Curve I, a siliceous cement and Curves II and III, ZnO cements.

Heat of Setting

No calorimetric data available. For temperature rise on setting *v.* ([2]).

LITERATURE

(For a key to the periodicals see end of volume)

([1]) Poetschke, *45*, **8**: 302; 16. ([2]) Poetschke, *45*, **15**: 339; 23.

SOLID FUELS

S. W. Parr

1. CLASSIFICATION

For the purpose of displaying typical values of their properties and compositions, solid fuels will be assigned to classes on the basis of two characteristics which will be called unit-heat-value (UHV) and unit-volatile-matter (UVM), respectively, and which are defined by the following equations ([17, 21]).

$$UHV = \frac{H - 5000S}{F}\ \text{BTU/lb.} = \frac{H - 2778S}{F}\ \text{g-cal/g}, \qquad (1)$$

where H is the total calorific value of the fuel (BTU/lb., g-cal/g, respectively); and

$$UVM = 100\left(\frac{V - (0.08 + 0.4S)}{F}\right)\%, \qquad (2)$$

where V = the volatile matter per unit mass of fuel.

In both equations the factor, $F = 1 - (W + 1.08A + 0.55S)$, where W, A and S are, respectively, the water, ash and sulfur content of the unit mass of fuel as determined by chemical analysis.

The numerical factors in equations (1) and (2) are such that the quantities UHV and UVM represent, respectively, the heating value and the volatile matter per unit mass of fuel-substance contained in the solid fuel; *see also* ([17, 21]).

By means of these two characteristics, every solid fuel can be represented as a point on a plane and the location of this point with respect to the areas which have been selected for delimiting the various classes of solid fuels, identifies the class to which the fuel belongs and its relative location in that class. This is illustrated by the diagram in Fig. 1. The circles represent the loci of certain selected samples, representative of each class, and whose compositions are shown in Table *A*. The crosses represent the loci of a series of coals corresponding to the composition averages of Tables 2–10.

Another method for classifying coals, based upon limits for carbon, hydrogen, oxygen plus nitrogen, and volatile matter has been proposed by Seyler ([27, 28, 29, 30]). The classes which he proposes are, however, in close agreement with those defined in Fig. 1 [*cf.* ([24])] and a comparison of the proposed nomenclatures is shown in the following table. All proposed nomenclatures are provisional, since no agreement has as yet been reached.

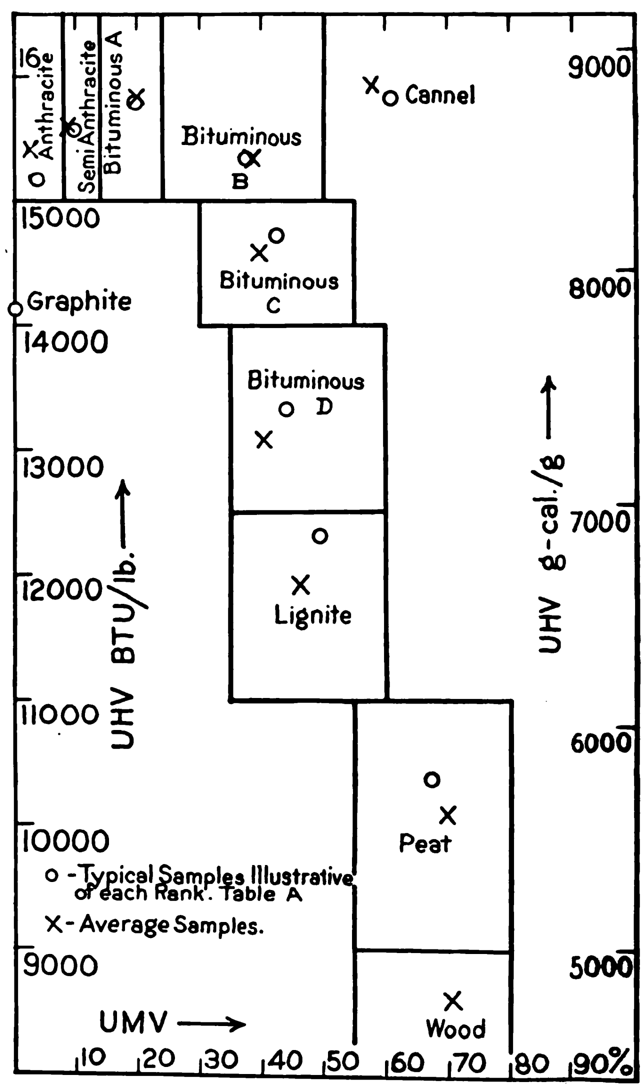


Fig. 1.—Classification of solid fuels.

TABLE A.—PERCENTAGE COMPOSITION OF TYPE SAMPLES OF SOLID FUELS

Type	State and county	Proximate				Ultimate					Air-dry loss	g-cal/g	BTU/lb	*UHV* BTU	*UVM*
		Volatiles	Fixed C	H_2O	Ash	S	H	C	N	O					
Anthracite	Schuylkill Co., Pa.	3.27	84.28	3.33	9.12	0.60	2.71	81.35	0.79	2.10	2.6	7 417	13 351	15 410	2.66
Semi-anthracite	Sullivan Co., Pa.	8.59	78.08	3.16	10.17	0.67	3.12	79.49	1.10	2.29	2.6	7 431	13 376	15 610	8.79
Bituminous A	McDowell Co., W. Va.	18.68	72.04	2.80	6.48	0.70	4.26	81.75	1.35	2.66	0.0	7 923	14 261	15 820	19.89
Bituminous B	Mingo Co., W. Va.	34.37	56.85	2.44	6.34	0.95	4.96	77.90	1.54	5.87	1.0	7 721	13 898	15 340	38.20
Bituminous C	Williamson Co., Ill.	32.92	48.30	9.94	8.84	1.28	4.24	66.18	1.46	8.06	4.4	6 508	11 714	14 590	39.71
Bituminous D	Moffat Co., Colo.	30.41	44.36	18.94	6.29	0.64	3.60	57.47	0.82	12.23	6.1	5 401	9 722	13 080	40.19
Lignite	El Paso Co., Colo.	24.44	27.27	34.40	13.89	0.14	2.64	35.94	0.66	12.33	26.4	3 364	6 055	11 930	46.20
Peat	Fond du Lac Co., Wis.	13.37	5.70	76.94	3.99	0.17	1.02	10.87	0.68	6.33	73.8	1 044	1 879	10 100	69.58
Wood	Air-dry	61.87	26.50	11.36	0.27		5.35	44.13	0.08	38.83		4 242	7 635	8 650	70.05
Cannel	Johnson Co., Ky.	50.64	36.70	2.20	10.46	0.99	6.33	72.01	1.17	6.84	1.3	7 638	13 748	15 920	57.55

TABLE B.—PERCENTAGE COMPOSITION OF TYPICAL WORLD COALS

Country and location	H_2O	Volatiles	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
England, Durham, Horden	1.50	34.68	59.15	3.80	0.87	13 330	7 420	14 140	36.20
England, Leicester, Nailstone	13.22	30.99	50.52	5.27	1.25	13 170	7 320	16 290	38.05
England, Yorkshire, Dearne Valley	8.44	37.01	51.19	2.00	1.36	13 397	7 440	15 020	40.90
Scotland, Ayrshire, Caprington	6.86	36.65	51.56	4.14	0.79	12 422	6 905	14 010	40.80
Scotland, Edinburgh, Newbattle	9.87	31.32	55.02	3.43	0.36	12 915	7 200	14 930	63.40
Scotland, Lanark, Coalburn	7.50	31.56	56.68	4.04	0.22	13 690	7 610	15 540	35.25
Wales, Cardiff	1.04	17.17	76.53	5.26	0.86	14 479	8 045	15 540	17.68
Wales, Neath	1.83	7.47	86.82	3.88	0.79	14 574	8 090	15 520	7.32
Wales, Port Talbot	2.41	11.65	70.49	15.45	1.01	13 124	7 310	16 260	12.48
Germany, Westphalia, Ruhr	0.30	6.00	87.60	6.10	0.90	14 080	7 822	15 100	5.90
Germany, Westphalia, Ruhr	0.80	12.40	79.50	7.30	1.40	13 940	7 745	15 300	12.42
Germany, Westphalia, Ruhr	2.60	29.20	64.20	4.00	0.80	13 760	7 644	14 810	30.80
Germany, Saar	1.73	33.16	57.54	7.57	0.94	13 896	7 720	15 450	35.90
Germany, Saxony	8.17	35.93	53.75	2.15	0.76	12 728	7 071	14 230	39.80
Germany, Saxony, brown coal	14.42	44.63	33.85	7.10	1.17	8 872	4 929	11 400	56.50
Bulgaria, Boronschtitza	0.72	36.05	56.43	5.30	3.01	12 690	7 050	13 650	37.50
Japan, Joban	12.24	40.61	36.11	11.04	1.02	9 759	5 423	12 900	52.20
Japan, Chihuko	4.21	42.92	45.71	7.33	0.68	12 965	7 205	14 780	48.10
S. Africa, Middleburg	2.57	29.16	57.68	10.59	0.42	12 392	6 885	14 425	32.45
S. Africa, Natal	1.28	23.70	67.06	7.96	1.24	13 720	7 622	15 271	25.01
Australia, New South Wales	1.89	41.35	50.51	6.25	1.01	12 760	7 090	14 000	41.50
Australia, New Zealand	0.70	16.68	77.67	4.95	0.30	14 915	8 286	15 890	17.20
Canada, Alberta, Crows Nest	2.10	23.10	58.60	16.20	0.50	12 400	6 888	15 420	26.95
Canada, New Brunswick, Minto	1.20	31.70	53.80	13.30	6.60	13 020	7 240	15 690	37.90
Canada, Nova Scotia, Sidney Field	3.70	35.00	54.20	7.02	2.79	13 150	7 306	14 910	37.40

TABLE 1.—CLASSIFICATION OF COALS

Type No.	Table No.	Type	Name	
		Parr	Common	Seyler
1	2	Anthracite	Anthracite	Anthracite
2	3	Semi-anthracite	Semi-anthracite	Carbonaceous
3	4	Bituminous A	Semi-bituminous or low volatile	Meta-bituminous (short flame)
4	5	Bituminous B	Bituminous (eastern field)	Ortho-bituminous (true bituminous)
5	6	Bituminous C	Bituminous (mid-continental field)	Para-bituminous (long flame)
6	7	Bituminous D	Lignite, black, or sub-bituminous	Lignitous
7	8	Lignite	Lignite, brown	Lignitous

TABLE 1.—CLASSIFICATION OF COALS.—(*Continued*)

Type No.	Table No.	Type	Name	
		Parr	Common	Seyler
8	9	Peat		
9		Wood		
10	10	Cannel		
11	11	Coke		
12		Semi-coke		
13		Briquettes		
14		Pulverized		

PERCENTAGE COMPOSITION OF U. S. COALS

TABLE 2.—TYPE 1, ANTHRACITE

State, county, and seam	H_2O	Vol.*	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Colo., Gunnison	2.70	3.32	88.15	5.83	0.80	14 099	7 840	15 510	2.79
Colo., Gunnison	4.86	6.96	81.87	6.31	0.81	13 468	7 475	15 300	6.98
N. Mex., Santa Fe	5.70	2.18	86.13	5.93	0.69	13 286	7 375	15 130	1.63
N. Mex., Santa Fe	7.55	7.25	75.88	9.32	0.76	12 101	6 725	14 720	7.55
Pa., Schuylkill	2.76	2.48	82.07	12.69	0.54	12 577	6 970	15 075	1.51
Pa., Schuylkill	2.80	1.16	88.21	7.83	0.89	13 298	7 380	15 010	0.24
Pa., Schuylkill	2.30	1.54	82.77	13.39	1.05	12 523	6 955	15 080	0.08
Pa., Schuylkill	3.33	3.27	84.28	9.12	0.60	13 351	7 415	15 410	2.66
Pa., Luzerne	1.31	5.68	85.87	7.14	0.42	13 777	7 645	15 150	5.44
Pa., Luzerne	2.19	5.67	86.24	5.90	0.57	13 828	7 680	15 120	5.77
Pa., Lackawanna	3.43	6.79	78.25	11.53	0.46	12 782	7 097	15 200	6.75
Utah, Washington, No. 6	8.21	4.41	58.02	29.36	2.28	8 908	4 948	14 920	2.05
Wash., Lewis, Primrose	7.40	4.80	52.00	35.80	0.74	8 200	4 555	15 530	1.20
Wash., Whatcom, Puget	4.40	7.40	76.00	12.23	0.96	12 590	6 998	15 360	7.37
Average	4.21	4.49	78.98	12.31	0.82	12 485	6 935	15 170	3.86

* Vol. = volatile matter.

TABLE 3.—TYPE 2, SEMI-ANTHRACITE

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Pope, Hartshorne	2.07	9.81	78.82	9.3	1.74	13 702	7 620	15 690	9.65
Col., Gunnison, Crested Butte	1.94	9.22	80.34	8.50	0.85	13 740	7 640	15 485	9.28
Pa., Sullivan	3.38	8.47	76.65	11.50	0.63	13 156	7 305	15 660	8.71
Pa., Sullivan	3.47	9.28	76.10	11.15	0.78	13 216	7 345	15 685	9.60
Pa., Sullivan	3.40	9.34	75.58	11.68	0.81	13 120	7 292	15 630	9.67
Pa., Sullivan	3.16	8.59	78.08	10.17	0.67	13 376	7 430	15 610	8.58
Utah, Washington, No. 4	7.02	10.30	60.61	22.07	4.06	10 408	5 787	15 290	10.35
Va., Montgomery, large	2.5	12.40	67.50	17.60	0.51	12 360	6 860	15 770	13.81
Wash., Lewis, Primrose	3.60	8.40	59.60	28.40	0.66	10 050	5 578	15 330	9.00
Average	3.39	9.53	72.58	14.48	1.19	12 570	6 980	15 580	9.83

TABLE 4.—TYPE 3, BITUMINOUS A

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Sebastian, Hartshorne	1.7	16.91	73.03	8.36	1.23	13 840	7 688	15 510	17.70
Md., Allegheny, Pittsburgh	2.43	19.02	71.19	7.36	1.04	14 087	7 822	15 730	20.12
Md., Garrett, Freeport	2.39	16.41	71.82	9.38	2.01	13 707	7 618	15 770	17.23
Okla., Haskell, Hartshorne	2.37	19.26	69.54	8.83	1.03	13 840	7 690	15 740	20.72
Pa., Cambria, Lower Freeport	2.87	21.44	69.23	6.46	1.52	14 177	7 875	15 690	22.74
Pa., Clearfield, Lower Kittanning	3.20	21.00	69.30	6.50	0.69	14 060	7 820	15 700	22.60
Pa., Somerset, Pittsburgh	3.04	19.59	70.33	7.04	0.74	14 175	8 045	15 920	21.10
Pa., Huntington, Fulton	1.65	17.48	72.26	8.61	1.55	14 076	7 825	15 850	18.31
Va., Tazewell, Pocahontas No. 3	2.85	21.25	71.43	4.47	0.59	14 620	8 128	15 830	22.40
W. Va., Fayette, Sewell	3.58	21.07	72.75	2.60	0.64	14 751	8 190	15 790	22.20
W. Va., McDowell, Pocahontas No. 4	2.87	14.91	78.39	3.83	0.81	14 809	8 235	15 920	14.33
W. Va., McDowell, Pocahontas No. 3	2.03	18.51	75.54	3.92	0.49	14 812	8 240	15 840	19.29
Average	2.58	18.90	72.06	6.45	1.02	14 246	7 915	15 795	19.87

TABLE 5.—TYPE 4, BITUMINOUS B

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ala., St. Clair, Harkness	2.28	33.07	54.63	10.02	1.76	13 333	7 405	15 410	36.77
Ala., Tuscaloosa, Jagger	1.60	24.98	68.55	4.87	0.51	14 697	8 155	15 800	26.28
Ala., Jefferson, Pratt	1.05	31.70	62.15	6.15	1.38	14 377	7 980	15 610	33.45
Ky., Letcher, Elkhorn	2.91	36.33	57.53	3.23	0.53	14 170	7 875	15 160	38.44
Ky., Harlan, Harlan	2.80	37.00	55.90	4.30	1.10	13 950	7 748	15 120	39.42
Ky., Whitley, Jellico	5.02	36.08	54.47	4.43	0.92	13 608	7 555	15 110	39.40

TABLE 5.—TYPE 4, BITUMINOUS B.—(*Continued*)

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ohio, Jefferson, Lower Freeport	3.50	37.98	51.08	7.44	3.09	13 286	7 377	15 140	41.78
Ohio, Tuscarawas, Lower Kittanning	4.49	40.55	47.43	7.53	2.93	12 958	7 200	14 960	45.25
Ohio, Belmont, Meigs Creek	4.34	38.95	45.50	11.21	3.65	12 402	6 895	14 990	49.85
Ohio, Guernsey, Pittsburgh	4.36	41.14	45.76	8.74	4.85	12 710	7 058	14 910	46.05
Pa., Washington, Washington	4.45	33.53	49.51	12.51	3.04	12 242	6 800	15 060	39.00
Pa., Westmoreland, Pittsburgh	2.73	30.34	57.80	9.13	1.33	13 613	7 556	15 610	33.47
Pa., Cambria, Upper Freeport	2.73	26.04	65.05	6.18	1.39	14 269	7 925	15 800	27.82
Pa., Jefferson, Lower Freeport	1.86	34.63	53.23	10.28	2.91	13 151	7 300	15 220	38.00
Va., Russell, Upper Banner	2.07	35.90	57.70	5.33	0.57	14 335	7 952	15 590	38.40
Va., Wise, Imboden	2.16	33.10	58.27	6.47	0.68	13 994	7 756	15 410	35.70
W. Va., Marion, Pittsburgh	1.75	36.77	55.14	6.34	0.90	14 107	7 845	15 490	39.50
W. Va., Randolph, Lower Kittanning	1.45	28.97	59.48	10.10	0.98	13 718	7 620	15 700	31.84
W. Va., Kanawha, Coalburg	3.44	35.20	53.08	8.28	0.70	13 304	7 396	15 220	39.50
W. Va., Kanawha, No. 2 gas	2.66	33.30	59.60	4.44	1.14	14 368	7 975	15 590	35.38
Average	2.85	34.27	55.59	7.35	1.71	13 630	7 580	15 330	37.40

TABLE 6.—TYPE 5, BITUMINOUS C

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ill., Vermilion, No. 7	13.16	37.95	39.02	9.85	4.33	11 110	6 175	14 760	46.60
Ill., Williamson, No. 6	9.44	32.99	48.95	8.62	0.93	11 858	6 594	14 470	39.10
Ill., Saline, No. 5	5.56	34.41	51.31	8.72	2.87	12 643	7 038	14 990	39.04
Ill., Sangamon, No. 5	13.09	36.51	41.14	9.26	3.77	10 935	6 075	14 360	45.70
Ill., Bureau, No. 2	16.27	38.35	38.00	7.38	2.93	10 883	6 045	14 480	49.25
Ill., Mercer, No. 1	15.58	39.17	35.80	9.45	4.69	10 673	5 927	14 570	50.98
Ind., Sullivan, No. 6	14.86	31.65	46.14	7.35	2.16	11 324	6 300	14 620	39.78
Ind., Vigo, Minshall	13.10	36.83	41.73	8.34	2.60	11 484	6 378	14 860	49.20
Iowa, Lucas	15.39	30.49	41.49	12.63	3.19	10 242	5 690	14 560	40.70
Iowa, Marion	14.21	33.17	37.40	15.22	4.66	10 019	5 573	14 640	45.00
Ky., Webster, No. 12	5.58	35.04	51.32	8.06	1.59	12 755	7 095	14 950	39.68
Ky., Hopkins, No. 14	8.85	35.29	47.51	8.35	2.79	11 921	6 625	14 595	41.51
Ky., Union, No. 9	4.37	36.27	47.67	11.69	3.58	12 325	6 852	14 985	41.80
Kans., Cherokee, Cherokee	5.11	32.60	53.39	8.90	4.34	12 926	7 185	15 320	36.40
Kans., Osage, Osage	5.10	36.85	48.10	9.95	5.02	10 930	6 070	14 970	47.58
Mo., Henry, Jordan	10.10	34.83	41.76	13.31	4.32	11 158	6 200	14 950	43.78
Okla., Pittsburg, Lower Hartshorne	4.33	35.51	54.04	6.12	0.84	13 574	7 548	15 260	39.15
Okla., Okmulgee, Henryetta	8.87	34.82	47.68	8.63	1.62	12 096	6 720	14 880	41.45
Average	10.16	35.15	45.13	9.54	3.12	11 603	6 460	14 720	42.55

TABLE 7.—TYPE 6, BITUMINOUS D

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Colo., Boulder	19.14	33.44	42.07	5.35	0.27	10 017	5 570	13 380	43.90
Colo., El Paso	19.23	32.34	41.41	7.02	0.45	9 306	5 170	12 780	43.43
Colo., Moffat	22.10	31.61	41.95	4.34	0.72	9 297	5 165	12 710	42.50
Colo., Weld	22.20	39.23	33.12	5.45	0.33	9 578	5 320	13 310	53.90
Mont., Choutou	16.83	27.89	43.78	11.50	1.19	9 563	5 315	13 575	37.69
Mont., Musselshell, Homestead	18.14	27.22	50.49	4.15	0.88	10 420	5 795	13 540	33.20
Mont., Park, Maxey	16.33	30.12	40.05	13.50	0.41	9 247	5 130	13 400	40.51
N. Mex., McKinley	13.50	37.75	42.51	6.24	0.36	11 140	6 195	13 990	46.65
N. Mex., San Juan	19.01	32.43	43.15	5.41	0.92	10 193	5 670	13 575	42.30
Utah, Summit	17.08	36.94	41.24	4.74	1.53	10 179	5 663	13 140	46.72
Wash., King, No. 1	16.45	34.63	36.38	12.54	0.38	9 581	5 335	13 690	47.96
Wash., Lewis	20.50	33.50	33.70	12.31	1.28	8 690	4 820	13 170	48.80
Wash., Thurston	21.00	33.10	36.70	9.20	0.42	8 910	4 950	12 910	46.78
Wyo., Carbon	13.62	34.55	43.14	8.69	1.44	10 339	5 745	13 480	43.60
Wyo., Hot Springs, Gebo	17.87	31.26	43.48	7.39	0.66	10 062	5 594	13 780	41.75
Wyo., Sheridan	22.57	32.53	40.36	4.55	0.30	9 218	5 123	12 710	44.34
Wyo., Sweetwater	15.71	33.50	48.40	2.39	0.93	11 144	6 185	13 670	40.55
Average	18.31	33.06	41.29	7.34	0.73	9 818	5 450	13 330	43.80

TABLE 8.—TYPE 7, LIGNITE

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Ouachita, Lignite	39.50	25.35	22.57	12.58	0.53	5 877	3 262	12 550	51.75
Colo., Adams	35.00	27.39	30.23	7.38	0.31	6 982	3 880	12 230	46.90
Colo., Elbert, Laramie	33.10	25.60	25.60	15.66	0.44	6 150	3 420	12 300	48.60
Colo., El Paso	34.40	24.44	27.27	13.89	0.14	6 055	3 362	11 930	46.20
N. D., Adams, Haynes	32.65	30.57	28.49	8.29	1.53	7 357	4 080	12 640	50.80
N. D., Billings	43.51	25.23	24.87	6.39	1.04	5 814	3 230	11 700	49.40
N. D., Bowman	34.80	31.09	25.98	8.13	0.66	6 916	3 840	12 270	53.80
N. D., Morton	38.52	27.60	26.60	7.28	1.31	6 703	3 722	12 530	50.15
N. D., Stark	42.06	24.55	25.73	7.66	1.13	6 158	3 420	12 440	47.80
N. D., Ward	36.93	24.92	27.72	10.43	0.22	6 010	3 340	11 610	46.40
N. D., Williams	42.91	26.81	24.98	5.30	0.71	6 232	3 460	12 160	49.30
Tex., Milam	35.30	26.22	29.58	8.90	0.76	6 898	3 830	12 540	46.15
Tex., Wood	33.71	29.25	29.76	7.28	0.53	7 348	4 075	12 600	50.70
Average	37.11	26.85	26.87	9.17	0.72	6 500	3 640	12 300	49.20

TABLE 9.—TYPE 8, PEAT

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Conn., Fairfield	90.31	3.79	1.27	4.63	0.08	511	284	10 900	82.68
Conn., New London	85.66	8.52	4.54	1.28	0.10	1 382	769	9 900	67.40
Fla., Duval	73.10	14.00	8.05	4.85	1.06	2 309	1 282	10 695	61.80
Fla., Lake	82.12	11.75	5.72	0.41	0.05	1 886	1 047	10 820	67.20
Fla., Putnam	80.78	9.72	6.32	3.18	0.40	1 661	924	10 520	59.80
Me., Aroostook	86.18	8.27	3.98	1.57	0.10	1 294	719	10 680	67.00
Me., Knox	90.82	6.07	2.73	0.38	0.02	819	455	9 350	68.80
Me., Washington	85.22	8.86	4.72	1.20	0.07	1 444	802	10 710	64.90
Mich., Kalamazoo	66.91	19.04	9.29	4.76	0.09	3 024	1 670	10 825	66.66
N. Y., Oswego	54.66	29.15	12.44	3.75	0.17	4 104	2 278	9 950	69.77
Wis., Dane	71.33	16.01	6.75	5.91	0.12	2 187	1 216	9 820	69.61
Wis., Langlade	80.24	9.21	4.17	6.38	0.13	1 256	697	9 780	67.40
Wis., Marinette	76.36	10.78	4.66	8.20	0.16	1 498	832	9 930	68.30
Average	78.74	11.93	5.74	3.57	0.19	1 798	999	10 370	66.80

TABLE 10.—TYPE 10, CANNEL COAL

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
Ind., Perry	1.47	49.08	26.35	23.10	1.50	10 850	6 030	14 810	64.0
Ky., Johnson, Cannel	2.36	48.40	38.75	10.49	1.20	13 770	7 645	16 010	54.9
Ky., Johnson, Lesley Cannel	1.7	50.7	38.2	9.3	1.02	14 250	7 915	16 190	56.5
Tenn., Campbell, Blue Gem	1.50	45.10	34.10	19.30	1.16	12 340	6 855	15 930	55.8
Tex., Webb, Cannel	3.98	48.87	34.91	12.24	1.96	12 227	6 790	14 830	57.65
Wash., Lewis, Cannel No. 3	7.88	61.57	15.11	15.44	0.29	11 920	6 630	15 810	79.26
W. Va., Boone, Chilton	0.52	50.92	35.82	12.74	1.10	13 830	7 680	16 200	57.95
W. Va., Boone, Cedar Grove	0.43	56.99	33.90	8.68	1.85	15 000	8 335	16 720	62.30
Average	2.48	51.45	32.14	13.91	1.26	13 023	7 230	15 820	60.85

TABLE 11.—ANALYSIS AND PHYSICAL PROPERTIES OF COKE AND WOOD CHARCOAL

Type	H_2O	Vol.	Fixed C	Ash	H	C	N	O	S	BTU/lb.	% porosity	lb./ft.^{3}
Jones and Laughlin	0.2	1.5	85.9	12.4	0.6	84.9	1.0	0.2	0.9	12 400	48.2	31
Continental No. 1	0.1	0.9	88.1	10.9	0.7	86.3	1.3	0.0	0.8	12 810	50.3	29
Leisenring No. 1	0.1	0.5	88.0	11.4	0.4	85.9	1.1	0.4	0.8	12 510	46.5	30.5
Wilkenson	0.2	0.5	80.3	19.0	0.4	78.9	1.4	0.0	0.5	11 690	54.1	27
Wood charcoal	3.2	20.0	72.8	4.0	3.7	78.7	0.4	13.1	0.1	12 920	63.2	17

CALORIFIC VALUE

The values characteristic of the different classes of solid fuels are evident from Fig. 1. The calorific value of a solid fuel of the fossil fuel type may be computed (1 to 2%) by means of the Du Long formula, $H = 8080C + 34\,500\left(H - \frac{O}{H}\right) + 2250S$, g-cal, where C = total carbon, $\left(H - \frac{O}{H}\right)$ = combustible hydrogen, and S = sulfur; *cf.* (34).

It may also be computed from equation (1) since the value of UHV is constant for a given mine or region and needs to be determined only once. For standard calorimetric methods, *v.* (5).

SULFUR CONTENT

For methods of differentiating between organic and inorganic S, *v.* (23). Distribution of the different forms, *v.* (19, 39, 40).

ASH FUSIBILITY

Methods (14, 26). Results for 2000 coals (26). Fusibility of coal ash by states and seams (41). Bibliography (7); *see also* (8, 25). Values range from 1040° to 1700°C.

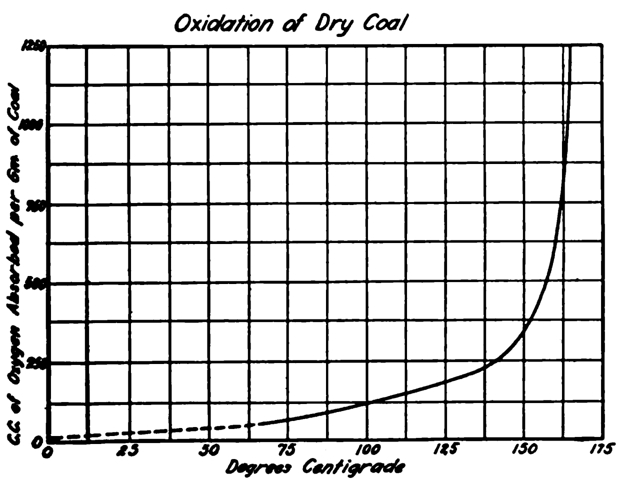


FIG. 2.—(*Courtesy Industrial and Engineering Chemistry.*)

DENSITY

True density, g/cm³; anthracite, 1.4–1.8; bituminous, 1.2–1.5; lignite, 1.1–1.4 (15). Coke, 1.45–2.0(35).

BULK DENSITY IN BIN OR PILE, ±10 TO 15% (9)

Size	lb./ft.³	kg/m³
Anthracite		
Buckwheat	55	888
Pea	54	870
Chestnut	56	891
Range	56	899
Egg	56	891
Furnace	54	866
Bituminous		
Screenings	51–52	820–830
Lump	48	774
Sub-bituminous		
Lump	45–46	720–737

Additional literature: (3, 11, 12, 42).

POROSITY

Methods (3). Coal—no data. Coke—29–59% (3); *v.* Table 11.

SPECIFIC HEAT

0.26 to 0.37 g-cal/g (22).

SPONTANEOUS COMBUSTION, WEATHERING AND DETERIORATION

Absorption of oxygen by powdered bituminous coal: Fig. 2 (18). Effect of storage on calorific power: Fig. 3 (20).

COKING BEHAVIOR

See (6, 10, 13, 14, 16, 32, 33, 37).

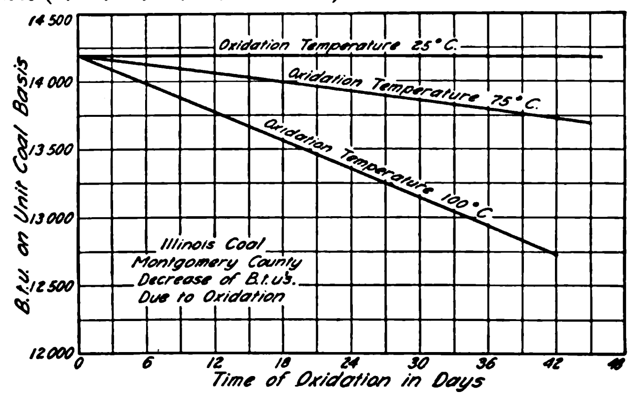


FIG. 3.—(*Courtesy Industrial and Engineering Chemistry.*)

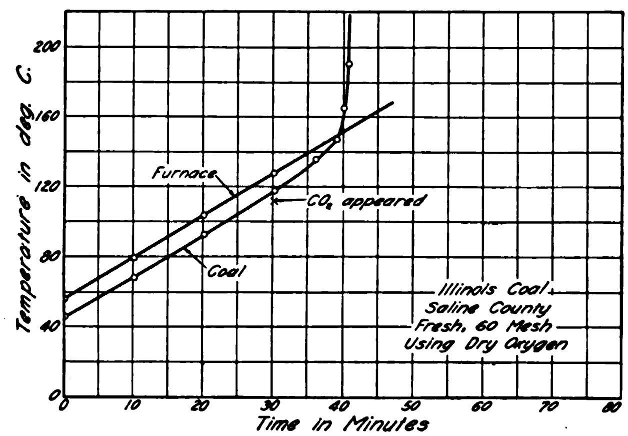


FIG. 4.—(*Courtesy Industrial and Engineering Chemistry.*)

IGNITION TEMPERATURES

The ignition temperature of a mass of coal is the temperature at which oxidation within the mass proceeds autogenously under the conditions of the experiment. Curves showing typical progress of heating within and without a 10 g sample of bituminous coal are shown in Figs. 4 and 5 (38). The following table (36) gives the ignition temperatures of various types of coal, using dry oxygen and 60 mesh "as-received" coal.

Type No.	CO_2 evolved at, °C	Ignition temp., °C
5	73	153
5	70	152
5	74	169
5	75	147
5	70	153
5	65	157
5	70	157
5	81	152
5	75	159
5	80	149
4	70	170
5	75	171
1	70	242
4	75	171
4	75	194
4	78	213
4	85	185

COMBUSTIBILITY OF COKE

A combustibility test is designed to show "the speed at which the carbon molecules in the coke combine with oxygen under given conditions" and is especially important in determining the value of a blast furnace coke. For method and results, *v.* ([31]).

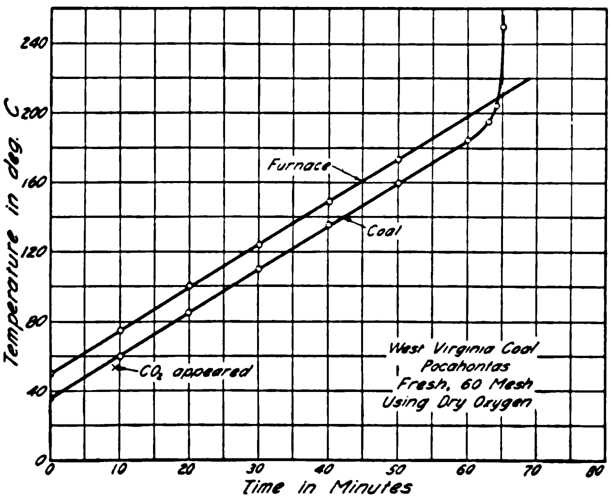


FIG. 5.—(*Courtesy Industrial and Engineering Chemistry.*)

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(For a key to the periodicals see end of volume)

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PETROLEUMS, PETROLEUM PRODUCTS AND COMMERCIAL OILS OF MINERAL ORIGIN

E. H. LESLIE AND J. C. GENIESSE

With acknowledgments to E. B. Badger and Sons Company of Boston for valued clerical assistance

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE

COMPOSITION AND DENSITY OF CRUDE PETROLEUMS

North America

Canada

Low boiling constituents are of the C_nH_{2n+2} series up to C_{10}. The C_nH_{2n} series starts at C_{11} and includes both straight-chain olefins and saturated naphthenes. The series poorer in hydrogen occur in the high boiling fractions. More aromatics present than in Pennsylvania or Ohio oils. Sulfur as thiophanes, $C_nH_{2n}S$ (121, 127, 135, 136, 172).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Bothwell............	0.857	0	84.3	13.4		2.3		(53.1)
Cherryvale..........			85.4	13.1			0.37	(53.1)
Great Manitoulin Is...	0.828	0	83.1	14.3		2.6		(53.1)
Humboldt............			85.6	12.4			0.37	(53.1)
Humboldt............			85.3	11.8			0.15	(53.1)
Oil Springs..........	0.844		83.6	13.4	0.18		0.6	(53.1)
Petrolia.............	0.862	20	83.9	13.4	0.16		1.01	(53.1)
Petrolia.............	0.870		84.5	13.5		2.0		(53.1)
Petrolia (169 m)......	0.844	0	82.7	13.5		3.8		(53.1)

United States

California.—Proportion of distillates below 225°C small to moderate and composed of methylenes similar in B. P. and sp. gr. to those in Russian oil, except for the compounds $C_{11}H_{22}$, $C_{12}H_{24}$ and $C_{13}H_{26}$. Proportion of aromatics large. Members of the C_nH_{2n+2} series absent (133). Organic bases mainly mixture of alkylated quinolines with small side chains (139). Oxygen usually as naphthenic acids with some phenolic compounds. Sulfur as $C_nH_{2n}S$.

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Adams Canyon..	0.921	30			1.46		0.90	(113)
Bardsdale.......	0.892	20	84.2	12.2	1.25		1.5	(113)
Coalinga*.......	0.951	15	86.4	11.7	1.14		0.60	(53.1)
Kern River.....	0.967	15	86.4	11.3	0.74		0.89	(53.1)
McKittrick.....			86.1	11.5			0.87	(113)
McKittrick.....	0 960	15	86.5	11.4	0.58		0.74	(53.1)
Midway........	0.958	15	86.6	11.6	0.74		0.82	(53.1)
Puente†........	0.892	20	85.0	12.0	1.20		0.80	(113)
Summerland....	0.985		86.3	11.7	1.25		0.84	(125)

California.—(*Continued*)

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Sunset..........	0.971	15	85.6	11.4	0.84		1.09	(53.1)
Torrey..........	0.884	20	86.0	12.5	1.15		0.5	(113)
Ventura.......			86.9	11.8	1.11			(113)
Ventura County	0.912		84.0	12.7	1.7	1.2	0.4	(15.1)
San Joaquin Valley...........	0.961	15.5	86.3	11.4	0.81		0.82	(7)
Fresno region...	0.842	20	86.2	13.1			0.21	(53.1)

* Contains hexane, benzene, toluene, xylene and 7 hydrocarbons of the C_nH_{2n} series (123).

† Contains naphthenes C_7H_{14}, C_8H_{16}, $C_{10}H_{20}$, $C_{11}H_{22}$. Paraffins above M. P. 95° absent. A considerable proportion of aromatics in distillate. Large proportion of naphthene in 221°–222° distillate.

Kansas.—Mixture of paraffin- and naphthene-base crude (172).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Chanute........			84.7	14.6	0.45		0.61	(165)
Humbolt........	0.912		85.6	12.4			0.37	(113)
Neodesha.......			84.0	13.1	0.81	0.04	0.88	(165)
Towanda.......			84.2	13.0	0.45		1.9	(165)

Ohio.—Paraffin-base predominates in the east. Heptylene and many alkyl sulfides have been isolated (129, 137).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Baltimore.......	0.824	20	84.2	14.6	0.08		0.61	(53.1)
Findlay.........	0.836		84.6	13.6	0.11		0.72	(113)
Heilstone Oil Co.	0.830	20	85.8	13.8	0.023		0.63	(53.1)
Liberty (Wood)..	0.843	20	85.1	13.3	0.056		0.76	(53.1)
Liberty (Hancock).........	0.828	20	84.2	13.4	0.35		0.68	(53.1)
Liberty (Hancock).........	0.835	20	84.0	13.1	0.047		0.71	(53.1)
Lima..........	0.851	20	85.0	13.1	0.024		0.81	(53.1)
Lima...........			85.0	13.8			0.60	(113)
Mahone*.......	0.904		86.4	13.3	0		0.01	(128)
Mecca..........			86.3	13.1	0.23			(53.1)
Montgomery ...	0.827	20	83.9	13.2	0.054		0.37	(53.1)
Ohio...........	0.887	0	84.2	13.1		2.7		(53.1)
Ohio (Wood)....	0.819	20	84.3	13.5	0.21		0.56	(53.1)
Portage.........	0.815	20	84.4	13.4	0.13		0.68	(53.1)
St. Mary's......	0.829	20	84.7	13.5	0.068		0.61	(53.1)
Trenton Limestone†........			85.5	13.9				

* Does not contain C_nH_{2n} or C_nH_{2n+2} series. The C_nH_{2n-2} series from C_{11} to C_{15} present in small amounts. Main constituents $C_{16}H_{28}$, $C_{17}H_{30}$ and $C_{18}H_{34}$. No nitrogen and only 0.01 % sulfur.

† Similar to Pennsylvania but larger proportion of aromatics. 0.2 to 0.5 % nitrogen. The $x = 0$, -2 and -4 series (C_nH_{2n+x}) present and 13 hydrocarbons isolated (129, 120.1).

UNITED STATES.—(*Continued*)

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Oklahoma.—Mixed paraffin- and asphaltic-base oils.								
Field not given			85.7	13.1	0.30		0.40	(113)
Healdton			85.0	12.9			0.76	(113)
Oregon.—Trace of aromatics (53.1).								
	0.960	20	86.1	11.9	0.87		1.19	(53.1)
Pennsylvania.—Typical paraffin-base oils. C_nH_{2n+2} series up to C_{35}. C_nH_{2n} series from C_{21} to C_{26}. Light lubricant fraction mainly x = − 2 series with some aromatics (C_nH_{2n+x}); x = − 4 and −8 series, and also series up to −16 have been identified (124, 126, 130, 172).								
Allegheny	0.886	0	84.9	13.7	1.4			(53.1)
Oil City	0.810		85.8	14.0	0.06			(113)
Oil Creek	0.816	0	82.0	14.8	3.2			(53.1)
Pennsylvania			86.1	13.9			0.06	(113)
Pennsylvania			85.8	14.0				(124)
Pa. pipe line	0.862	15	85.5	14.2				(53.1)
Texas								
Beaumont*	0.91		85.7	11.0	2.61		0.7	(53.1)
Beaumont*	0.912		85.0	12.3	0.92		1.75	(173)

* Sulfur as organic, H_2S, and free. Oil composed largely of bicylic polymethylenes with small amount unsaturated hydrocarbons and their sulfur derivatives. x = −2 and −4 series (C_nH_{2n+x}) present and also higher series up to −20 (130, 122, 131, 174).

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Utah								
			86.9	11.9	0.02		0.64	(53.1)
West Virginia.—Similar to Pennsylvania.								
Rogers Gulch	0.857	0	83.2	13.2	3.6			(53.1)
Mecook	0.897	0	83.6	12.9	3.5			(53.1)
White Oak	0.873	0	83.5	13.3	3.2			(53.1)
Burning Springs	0.841	0	84.3	14.1	1.6			(53.1)
Cumberland			85.2	13.4	0.54			(113)

MEXICO (31, 32)

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Crude—no location given	0.929	15	84.2	11.4	0.8		3.6	
	0.940	15	83.8	11.3	1.1		3.8	
	0.970	15	83.0	11.0	1.7		4.3	

South America

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Argentina	0.928	15	86.7	12.1	1.0		0.2	(31, 32)
Argentina	0.939	15	86.2	11.7	1.8		0.3	(31, 32)
Argentina (San Rafael)	0.993	15	87.0	10.8	0.9		1.3	(31, 32)
(El Quemado)	0.960	15					0.5	(119)
*Colombia**	0.948	20	85.62	11.91	0.54			(134)

* Mainly the C_nH_{2n} series with some aromatics.

Europe

FRANCE

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Alsace								
Pechelbronn (tar product)	0.892	0	85.7	12.0	2.3			(169)
Pechelbronn (wet)	0.891	15	85.9	12.3	1.2		0.6	(31, 32)
Pechelbronn (dried)	0.906	15	86.4	12.1	0.8		0.7	(31, 32)
Pechelbronn (dry)	0.908	15	86.0	12.0	1.2		0.8	(31, 32)
Pechelbronn	0.912	0	86.9	11.8	1.3			(169)
Pechelbronn	0.908	0	85.6	9.6	4.75			(169)
Schwabweiler	0.829	0	79.5	13.6	6.9			(169)
Schwabweiler	0.861	0	86.2	13.3	0.5			(169)
Gabian	0.894	0	86.1	12.7		1.2		(169)

GERMANY

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Hanover	0.941	15	86.5	11.6	0.7		1.2	(31, 32)
Odesse	0.892	0	80.4	12.7	6.9			(53.1)
Oberg	0.944	0	84.4	11.5	4.1			(53.1)
Wietze	0.955	0	86.2	11.4	2.4			(53.1)

ITALY

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Pavia, Retorbido	0.979	0	86.4	12.2	1.4			(53.1)
Parma								
Neviano di Rossi	0.809	0	81.9	12.5	5.6			(53.1)
Marzolaro	0.938	0	84.9	11.4	3.7			(53.1)
Sala Braganze	0.786	0	84.0	13.4	1.8			(53.1)
Terra di Lavoro	0.970	21	83.6	10.8				(53.1)

POLAND

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Galicia. C_nH_{2n} series present. No olefins but some aromatics.								
East Galicia	0.870	0	82.2	12.1	5.7			(109)
West Galicia	0.885	0	85.3	12.6	2.1			(53.1)
Boryslaw	0.845	15	84.4	14.3	1.34			(53.1)
Harklowa	0.903	15	84.4	14.4	1.25			(53.1)
Justa Nowice	0.863	15	85.3	14.4	0.20		0.11	(53.1)
Kosmacz	0.867	15	85.5	13.9	0.57			(53.1)
Mraznica	0.880	15	84.6	14.0	1.25		0.14	(53.1)
Schodniza			85.0	14.1	0.86		0.027	(53.1)
Urycz	0.886	15	84.9	14.1	0.84		0.16	(53.1)
Wankowa-Brelikow	0.854	15	85.3	14.4	0.11		0.19	(53.1)
Not definitely located	0.855	15	86.5	13.0	0.2		0.3	(31)
Not definitely located	0.871	15	86.8	12.6	0.3		0.3	(31)

RUMANIA [*cf.* (66)]

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Crude (location not given)	0.928	15	86.8	12.1	0.7		0.4	(31)
	0.940	15	87.2	11.3	1.1		0.4	(31)
	0.947	15	87.1	11.5		1.0	0.4	(31)
Apostolache	0.828	15	85.5	14.1			0.19	(53.1)
Baicoi	0.773	15	84.1	14.8			0.09	(53.1)
Berca	0.801	15	85.6	14.0				(53.1)

RUMANIA [*cf.* (66)].—(*Continued*)

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Bisoca	0.877	15	85.2	13.9				(53.1)
Bustenari	0.842	15	86.3	13.3			0.18	(53.1)
Campeni Parjol	0.773	15	85.3	14.2			0.03	(53.1)
Campina	0.848	15	86.0	13.3			0.13	(53.1)
Casin	0.800	15	85.1	13.8			0.14	(53.1)
Comanesti	0.839	15	85.2	14.2				(53.1)
Dofteana Pacuritza	0.847	15	86.1	13.0			0.21	(53.1)
Glodeni	0.833	15	85.6	13.9				(53.1)
Gura Ocnitzei	0.870	15	85.9	13.1				(53.1)
Lucacesti	0.873	15	85.9	13.3			0.28	(53.1)
Matitza-Maora	0.878	15	85.5	13.9			0.05	(53.1)
Mosoarele	0.836	15	85.5	13.4				(53.1)
Pacuretzi	0.811	15	85.9	13.3			0.08	(53.1)
Poiana-Verbilau	0.804	15	85.4	13.9			0.07	(53.1)
Recca	0.875	15	86.2	12.8			0.16	(53.1)
Sarata Monteoru	0.876	15	85.4	13.2			0.33	(53.1)
Solontzi	0.840	15	86.5	13.2			0.17	(53.1)
Stanesti	0.846	15	86.0	13.0			0.06	(53.1)
Tega	0.893	15	86.5	12.9				(53.1)
Tetzcani Antal	0.791	15	85.9	13.4			0.14	(53.1)
Tetzcani Sarbi	0.832	15	85.7	13.3				(53.1)
Tetzcani Vatra	0.792	15	85.2	14.0				(53.1)
Wallachei (Ploesti)	0.862	0	82.6	12.5		4.9		(53.1)
	0.901	0	83.0	12.2		4.8		(53.1)

RUSSIA

Crude (no location given)	0.876	15	86.3	12.9	0.6		0.2	(31)
	0.902	15	86.1	12.8	0.9		0.2	(31)

Baku.—Low boiling distillate is of the C_nH_{2n} series. Aromatics 85–250°C. The high boiling distillate contains the x = −6, −8, −10, −12, and −20 series (C_nH_{2n+x}) and small amount naphthenic acids (130, 142).

Baku	0.897		86.5	12.0		1.5		(53.1)
Baku	0.954		85.3	11.6		3.1		(53.1)
Benkendorff			86.6	13.4				(53.1)
Benkendorff			87.0	13.2				(53.1)
Benkendorff			86.9	13.2				(53.1)
Baku (av. analysis)			86.0	13.0		1.0		(53.1)
Balachany-Ssabuntschi	0.882		87.4	12.5		0.1		(53.1)
Binagady	0.913		85.5	12.0	2.4		0.41	(53.1)

Caucasian.—Almost entirely naphthene hydrocarbons. Small amounts of phenols, naphthenic acids and other aromatics (143).

Caucasian			86.9	13.3			0.064	(143)
Caucasian	0.940	20	85.3	11.6		3.1		(169)
Caucasian	0.887	0	84.2	12.4		3.4		(169)
Fergana-Tschimeon	0.872		85.8	13.6			0.08	(53.1)
Grozni	0.850		86.0	13.0	0.07	0.74	0.14	(53.1)
Grozni	0.906		86.4	13.0	0.07	0.4	0.10	(53.1)
Transcaspian			86.9	12.2		0.80	0.16	(53.1)
Transcaspian	0.873		86.6	12.4	0.14	0.37		(53.1)
Tscheleken	0.874		86.4	12.4		0.38		(53.1)
Uchta	0.928		85.5	12.2	0.20	1.03	1.09	(53.1)
Uchta	0.897		85.3	12.5	0.14	1.21	0.88	(53.1)

Africa—EGYPT

	0.907	15.5	85.15	11.71	0.892		2.25	(82)

Mixture of paraffin- and asphalt-base oils rich in sulfur.

Asia—INDIA

Assam								
Digboi*	0.856	15.5	86.3	12.9	0.2	0.45	0.15	(216)
Badarpur†			88.8	10.8	0.2	0.1	0.1	(216)
Burma‡	0.835		86.45	13.25	0.2		0.1	(216)
Rangoon§	0.875	28.2	83.8	12.7	3.5			(169)

* Mixed-base oil with small amount naphthenic acid. Low-boiling distillate contains aromatics.

† No solid paraffins and little asphalt. Empirical composition $C_nH_{1.47n}$.

‡ Mixed-base petroleum containing solid paraffins and asphalt. Aromatics and small amounts of naphthenic acids in the lighter distillates.

§ $C_{20}H_{26}$, $C_{22}H_{22}$, $C_{24}H_{24}$, $C_{26}H_{26}$, xylene and isocumene isolated (205).

JAPAN (138)

Chiefly the C_nH_{2n} series. Aromatics much smaller than in California.

Amaze	0.8240	20	84.66	13.22	0.35	1.32	0.22	
Hirei	0.8622	20	83.28	13.19	0.74	1.83	0.41	
Katsubo	0.8771	20	84.52	13.12	0.97	0.21	0.82	
Kitatany	0.8952	20	83.05	13.05	0.75	0.24	0.61	
Koguchi	0.9435	20	83.91	13.60	1.34	0.41	0.49	
Kosudsu	0.9210	20	84.49	13.40	1.23	0.30	0.37	
Miyagawa	0.8911	20	84.86	13.83	0.5	0.20	0.32	

PERSIA

Maidan-I-Naftun*	0.837		85.4	12.8	0.76		1.06	(47)

* Mixed-base oil. Gasolene fraction contains *ca.* 10 % aromatics.

East Indies—BORNEO

Sarawak*	0.902	15	86.47	12.37	0.13	0.68	0.35	(104)

* Naphthene-base oil, with paraffin-base oils at the 1950-foot level. Small amounts aromatics.

JAVA

Rembang	0.923	0	87.1	12.0		0.9		(169)
Cheribon	0.827	0	83.6	14.0		2.4		(169)
Surabaya	0.972	0	85.0	11.2		2.8		(169)

PROXIMATE COMPOSITION

For comprehensive tables covering the chief producing fields of the world *see* (39, 53.1); for extensive tables of data on North and South American crudes, *see* (108).

Below are given the data for the oil fields of the United States as collected from the reports of the U. S. Bureau of Mines, Reports of Investigations, Nos. 2293, 2595, 2608, 2235, 2364, 2322, 2202, 2416.

The various fractions ("cuts") used in these tables are defined by their distilling ranges or by their Saybolt viscosities (η) at 100°F as follows:

1. Gasolene and naphtha. Below 200°C at 1 atm.
2. Kerosene. Between 200° and 275°C at 1 atm.
3. Gas oil. All vacuum fractions (p = 40 mm) with $\eta < 50$ sec.
4. Light lubricating distillate. All vacuum fractions (p = 40 mm) with η between 50 and 99 sec.
5. Medium lubricating distillate. All vacuum fractions (p = 40 mm) with η between 100 and 199 sec.
6. Viscous lubricating distillate. All vacuum fractions (p = 40 mm) with $\eta > 199$ sec.

Specific gravities (d) are at 60/60F = 15.5/15.5C. % S = % sulfur.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates: Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
ARKANSAS															
El Dorado	Union	0.83	0.852	30.7	0.735	13.0	0.823	12.0	0.857	11.3	0.882	4.6	0.903		
El Dorado	Union	.79	.853	28.8	.736	12.8	0.824	12.5	.853	10.8	.880	5.6	.908		
CALIFORNIA															
Coalinga (Eastside)	Fresno	.67	.880	19.8	.775			34.1	.863	9.4	0.877–0.904	6.2	0.904–0.913	1.7	0.913–0.915
Coalinga (Eastside)	Fresno	.71	.919	9.2	.782			29.9	.866	7.9	.901– .925	6.5	.925– .938	9.0	.938– .953
Coalinga (Eastside)	Fresno	.45	.910	14.7	.782			29.4	.870	10.2	.898– .918	5.8	.918– .928	7.7	.928– .940
Coalinga (Eastside)	Fresno	.51	.930	6.8	.804			26.8	.871	11.4	.906– .930	7.3	.930– .940	7.9	.940– .953
Coalinga (Oil City)	Fresno	.10	.839	53.0	.788			36.8	.886						
Coalinga (Westside)	Fresno	.71	.963	2.2	.808			18.7	.873	12.0	.901– .926	7.7	.926– .943	8.3	.943– .961
Belridge	Kern	.86	.911	23.8	.776			21.0	.872	5.5	.909– .926	5.0	.926– .940	11.4	.940– .956
North Belridge	Kern	.79	.885	33.4	.781			22.0	.854	6.1	.891– .913	3.8	.913– .929	7.3	.929– .946
North Belridge	Kern	.69	.875	34.5	.785			24.7	.855	6.3	.887– .911	4.4	.911– .924	6.1	.924– .938
Buena Vista	Kern	.50	.869	36.0	.761			21.8	.862	5.7	.904– .921	3.7	.921– .932	6.9	.932– .948
Buena Vista	Kern	.59	.890	28.0	.778			23.4	.864	6.5	.901– .920	6.5	.920– .936	6.7	.936– .946
Buena Vista	Kern	.59	.894	26.9	.783			23.1	.860	6.6	.896– .916	5.1	.916– .932	8.0	.932– .946
East Elk Hills	Kern	.68	.915	12.3	.781			31.4	.860	7.6	.905– .923	7.1	.923– .935	6.7	.935– .948
East Elk Hills	Kern	.61	.895	24.0	.786			25.0	.872	7.1	.900– .918	5.7	.918– .933	6.9	.933– .947
East Elk Hills	Kern	1.04	.948					27.2	.870	7.8	.908– .929	5.9	.929– .937	12.5	.937– .955
West Elk Hills	Kern	0.17	.773	81.1	.754	5.1	.816								
West Elk Hills	Kern	1.06	.917	12.2	.783			29.7	.858	7.2	.891– .916	3.3	.916– .923	9.8	.923– .953
Kern River	Kern	1.14	.977					16.0	.874	9.9	.910– .935	4.1	.935– .945	13.9	.945– .968
Kern River	Kern	1.07	.972					14.0	.868	6.1	.907– .928	5.3	.928– .943	15.1	.943– .960
Kern River	Kern	0.94	.971					12.2	.873	6.5	.901– .921	5.0	.921– .934	15.8	.934– .966
Lost Hills	Kern	0.85	.956	5.1	.798			19.0	.868	8.8	.917– .940	5.5	.940– .953	12.4	.953– .967
Lost Hills	Kern	0.99	.944	7.6	.777			23.6	.871	7.0	.914– .937	4.6	.937– .948	11.5	.948– .962
Lost Hills	Kern	0.66	.879	31.5	.766			20.4	.852	7.5	.883– .902	4.6	.902– .917	6.1	.917– .927
Maricopa Flat	Kern	1.07	.941	13.3	.759			20.9	.871	5.9	.916– .933	3.9	.933– .944	13.6	.944– .970
Maricopa Flat	Kern	0.60	.892	27.2	.771			21.9	.867	7.0	.904– .922	4.0	.922– .937	9.9	.937– .958
Maricopa Flat	Kern	0.75	.925	18.4	.790			21.5	.873	6.8	.913– .931	4.5	.931– .941	12.6	.941– .965
Maricopa Flat	Kern	0.69	.893	23.9	.772			21.1	.860	7.0	.884– .904	5.4	.904– .916	6.7	.916– .928
Maricopa Flat	Kern	1.29	.983					16.6	.877	5.3	.919– .934	5.0	.934– .948	18.3	.948– .974
Maricopa Flat	Kern	0.68	.895	24.1	.774			21.5	.859	7.1	.886– .903	5.2	.903– .915	8.9	.915– .928
McKittrick	Kern	1.02	.965	2.1	.810			19.9	.873	6.9	.911– .932	6.6	.932– .950	17.2	.950– .988
McKittrick	Kern	0.91	.943	11.1	.796			22.3	.874	7.1	.913– .934	5.9	.934– .951	14.4	.951– .970
McKittrick (front)	Kern	1.38	.982					14.5	.878	6.6	.910– .931	6.6	.931– .949	19.9	.949– .984
Midway	Kern	1.00	.967					15.4	.844	7.6	.916– .935	5.4	.935– .950	17.4	.950– .968
North Midway	Kern	0.96	.982					10.8	.880	9.8	.899– .931	5.5	.931– .948	16.6	.948– .978
North Midway	Kern	0.88	.936	7.1	.787			26.7	.870	8.3	.907– .932	4.1	.932– .936	11.9	.936– .963
North Midway	Kern	0.98	.962	3.3	.806			17.5	.879	7.3	.911– .930	5.1	.930– .943	16.7	.943– .966
North Midway	Kern	1.01	.978					15.4	.880	7.4	.909– .937	6.0	.937– .952	16.3	.952– .971
North Midway	Kern	1.63	.987					10.2	.887	7.7	.909– .935	5.4	.935– .949	19.9	.949– .971
North Midway	Kern	1.01	.971					18.2	.874	8.4	.910– .933	6.2	.933– .949	13.7	.949– .977
North Midway	Kern	0.92	.936	9.6	.778			23.7	.874	7.2	.909– .926	4.7	.926– .936	14.4	.936– .958
Sunset	Kern	1.16	.981					19.3	.877	5.2	.904– .928	5.5	.928– .943	20.9	.943– .969
Sunset	Kern	0.84	.956	2.9	.824			18.3	.872	8.2	.889– .912	5.7	.912– .936	10.2	.936– .957
Sunset	Kern	0.73	.878	17.0	.777			26.9	.865	7.5	.908– .923	6.3	.923– .935	8.5	.935– .952
Brea	Los Angeles	2.99	.984	6.6	.805			19.4	.875	6.5	.913– .943	3.0	.943–. 950	16.4	.950– .975
Coyote Hills	Los Angeles	1.46	.899	20.5	.764	4.7	.819	17.9	.847	8.2	.873– .898	5.6	.898– .911	5.7	.911– .924
Long Beach	Los Angeles	1.25	.904	18.9	.763	5.7	.821	17.5	.857	7.0	.882– .903	4.7	.903– .917	5.6	.917– .931
Long Beach	Los Angeles	1.29	.897	19.8	.755	3.7	.823	17.3	.854	8.0	.879– .905	4.5	.905– .917	7.2	.917– .936
Long Beach	Los Angeles	0.80	.872	29.3	.757	4.4	.818	17.7	.848	8.8	.874– .901	5.0	.901– .914	4.2	.914– .926
Long Beach	Los Angeles	1.16	.892	24.1	.762	4.1	.818	17.5	.852	7.2	.879– .898	5.2	.898– .912	5.0	.912– .931
Long Beach	Los Angeles	1.59	.908	15.8	.768			19.4	.850	6.8	.884– .907	5.3	.907– .920	8.1	.920– .938
Long Beach	Los Angeles	1.34	.920	20.0	.763	4.5	.824	16.6	.856	6.5	.884– .905	5.7	.905– .921	7.2	.921– .934
Montebello	Los Angeles	0.96	.951					19.4	.876	10.2	.905– .925	7.3	.925– .936	9.2	.936– .947
Montebello	Los Angeles	2.19	.954	6.7	.785			25.9	.867	5.2	.905– .920	5.1	.920– .929	7.0	.929– .950
Montebello	Los Angeles	0.79	.916	11.1	.794			25.4	.864	10.2	.885– .905	6.5	.905– .916	8.7	.916– .928
Montebello	Los Angeles	0.75	.916	10.6	.800			28.1	.866	9.8	.890– .907	9.3	.907– .920	6.9	.920– .929
Salt Lake	Los Angeles	2.73	.967	8.3	.793			12.8	.868	6.0	.897– .918	7.1	.918– .942	13.5	.942– .964
Santa Fe Springs	Los Angeles	0.54	.867	27.9	.769			31.3	.852	9.2	.873– .894	3.2	.894– .901		
Santa Fe Springs	Los Angeles	0.56	.878	24.6	.778			27.7	.850	10.8	.870– .894	5.4	.894– .907	2.1	.907– .915
Santa Fe Springs	Los Angeles	0.45	.851	36.7	.760	5.3	.819	20.3	.848	8.9	.870– .898	2.9	.898– .907	4.4	.907– .919
Santa Fe Springs	Los Angeles	0.54	.888	18.8	.788			30.8	.850	10.2	.875– .897	4.8	.897– .908	5.8	.908– .921
Santa Fe Springs	Los Angeles	0.45	.853	35.5	.758	5.3	.821	20.3	.850	8.0	.871– .894	4.6	.894– .906	3.1	.906– .912
Santa Fe Springs	Los Angeles	0.45	.854	35.4	.763	5.1	.823	19.0	.847	9.9	.868– .898	3.6	.898– .905	4.0	.905– .913
Santa Fe Springs	Los Angeles	0.40	.855	34.3	.763	5.5	.822	20.8	.851	8.6	.875– .899	6.7	.899– .912	1.2	.912– .914
Santa Fe Springs	Los Angeles	0.44	.859	33.3	.763	6.3	.823	20.1	.850	9.5	.873– .901	4.9	.901– .909	3.0	.909– .914
Torrence	Los Angeles	1.62	.917	14.6	.774			21.5	.853	10.0	.884– .911	5.1	.911– .921	4.3	.921– .930
Whittier	Los Angeles	0.56	.916	18.8	.795			26.4	.869	6.5	.905– .922	4.7	.922– .936	10.3	.936– .951
Whittier	Los Angeles	0.77	.942	8.2	.804			22.4	.872	9.4	.901– .924	4.1	.924– .935	6.3	.935– .949
Fullerton	Los Angeles	1.43	.920	18.1	.771			21.3	.858	7.6	.887– .909	6.7	.909– .923	5.3	.923– .933
Huntington Beach	Orange	1.42	.905	18.4	.750	3.7	.817	15.6	.846	9.2	.869– .896	5.2	.896– .911	5.0	.911– .923
Huntington Beach	Orange	1.29	.897	22.3	.763	4.1	.821	17.2	.853	7.9	.879– .903	5.2	.903– .917	4.9	.917– .929
Huntington Beach	Orange	2.22	.968	2.1	.806			17.8	.867	6.7	.901– .924	5.6	.924– .937	8.0	.937– .950

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates: Light		Lubricating distillates: Medium		Lubricating distillates: Heavy	
		% S	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$
CALIFORNIA—(*Continued*)															
Huntington Beach	Orange	2.00	0.938	12.0	0.790			19.8	0.858	7.1	0.889–0.910	5.0	0.910–0.923	7.2	0.923–0.940
Huntington Beach	Orange	1.31	.892	25.0	.764	3.5	0.825	16.2	.853	7.0	.878– .900	5.4	.900– .915	5.9	.915– .925
Huntington Beach	Orange	2.07	.922	16.7	.769	3.3	.825	17.1	.854	7.7	.883– .911	4.4	.911– .922	6.5	.922– .934
Rich	Orange	1.09	.920	14.7	.785			21.0	.859	7.9	.884– .906	6.4	.906– .919	5.0	.919– .929
Richfield	Orange	1.60	.899	25.2	.752	3.8	.821	16.8	.854	7.7	.876– .903	5.9	.903– .919	6.9	.919– .933
Casmalia	Santa Barbara	2.84	1.023					26.8	.842	2.0	.897– .917	12.7	.917– .966	7.6	.966– .982
Cat Canyon	Santa Barbara	4.13	.960	9.8	.781			25.5	.854	5.6	.906– .923	5.6	.923– .936	7.8	.936– .949
Santa Maria	Santa Barbara	2.63	.916	21.8	.768			21.2	.856	6.6	.893– .916	4.5	.916– .929	5.7	.929– .943
Summerland	Santa Barbara	0.54	.975					14.8	.873	6.6	.913– .939	5.5	.939– .956	13.1	.956– .978
Sargent	Santa Clara	0.86	.952	8.3	.776			23.3	.878	7.7	.920– .944	4.1	.944– .953	11.7	.953– .972
Arroyo Grande	San Luis Obispo	1.30	.967	5.3	.805			17.3	.872	6.2	.904– .926	4.2	.926– .939	11.9	.939– .963
Bardsdale	Ventura	0.83	.873	26.8	.762	5.1	.817	20.0	.844	9.3	.873– .902	7.3	.902– .918	2.3	.918– .923
Conejo	Ventura	0.52	.970					11.0	.885	8.4	.902– .920	7.6	.920– .935	20.7	.935– .959
Ojai	Ventura	1.63	.952	13.0	.780			18.6	.869	6.5	.907– .932	4.6	.932– .947	10.9	.947– .963
Santa Paula	Ventura	0.55	.918	13.1	.789			29.5	.860	7.4	.899– .923	3.6	.923– .936	12.4	.936– .945
Simi	Ventura	0.68	.864	32.9	.759	5.2	.820	18.9	.853	7.4	.876– .900	4.6	.900– .915	5.4	.915– .929
South Mountain	Ventura	1.73	.886	25.5	.753	4.5	.817	16.9	.848	8.7	.871– .899	7.0	.899– .915	2.1	.915– .922
Ventura	Ventura	1.15	.875	28.6	.749	4.4	.820	17.2	.847	8.5	.873– .898	4.9	.898– .911	4.5	.911– .923
Ventura	Ventura	0.47	.794	64.4	.757	15.9	.812	8.1	.843						
Ventura	Ventura	0.90	.880	22.4	.756	11.0	.816	15.2	.847	14.1	.865– .902	7.5	.902– .917	1.2	.917– .920
Composite sample	Ventura	1.79	.907	23.7	.757	4.5	.825	17.1	.858	8.3	.882– .912	4.6	.912– .923	5.6	.923– .936
COLORADO															
Florence	Fremont and Pueblo	0.17	.880	8.9	.758	14.5	.808	16.2	.842	13.3	0.871	8.3	0.892		
Rangely	Rio Blanca	.06	.819	34.6	.748	19.3	.810	12.3	.844	11.7	.860	5.6	.880		
ILLINOIS															
	*	.24	.863	20.4	.769	14.5	.834	8.0	.856	10.7	.877	6.0	.893		
INDIANA															
Lima	†	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885		
KANSAS															
Iola	Allen	.66	.937	.8	.800	8.4	.842	4.7	.876	14.0	.891	8.2	.907	6.9	0.923
Moran and Elsmore	Allen	.32	.875	20.2	.758	15.3	.826	6.9	.856	12.6	.875	10.8	.898		
Augusta	Butler	.41	.865	24.2	.761	20.5	.830	11.1	.863	11.4	.890	5.5	.904		
Cattlemen	Butler	.30	.838	32.8	.736	15.3	.819	9.8	.859	10.0	.879	5.1	.895		
Elbing	Butler	.29	.856	29.8	.751	20.7	.826	13.3	.864	10.8	.888	5.0	.908		
Eldorado	Butler	.29	.853	27.3	.754	20.5	.822	12.1	.861	11.1	.885	5.7	.902		
Potwin	Butler	.14	.807	45.0	.730	17.1	.813	9.9	.850	8.2	.872	3.9	.890		
Peru Sedan	Chautauqua	.25	.875	19.0	.760	16.6	.824	10.7	.863	6.4	.876	11.0	.895		
Peru Sedan	Chautauqua	.24	.882	12.6	.791	18.4	.839	5.3	.863	14.9	.878	14.0	.895		
Peru Sedan	Chautauqua	.12	.858	20.6	.755	17.1	.817	11.3	.856	11.9	.875	7.3	.891		
Peacock	Cowley	.23	.853	25.9	.763	20.2	.821	11.2	.860	11.7	.878	6.3	.896		
Elrod	Cowley	.20	.853	25.9	.753	18.6	.820	11.2	.858	10.9	.878	6.7	.897		
New Albany	Elk	.27	.866	24.7	.748	13.9	.822	10.7	.857	9.9	.878	5.5	.896		
Rantoul	Franklin	.51	.880	22.4	.740	14.0	.824	9.2	.864	5.8	.878	6.7	.898		
Sallyyard	Greenwood and Butler	.24	.839	33.2	.737	16.6	.821	9.8	.857	9.7	.877	5.0	.893		
Tester	Greenwood	.19	.841	30.1	.752	18.5	.819	11.3	.857	10.9	.875	5.3	.895		
Florence and Peabody	Marion	.23	.861	25.1	.761	18.2	.829	13.3	.859	12.1	.884	6.4	.901		
Osawatomie	Miami	.57	.892	17.1	.753	16.3	.820	9.8	.862	5.5	.880	11.8	.901		
Independence	Montgomery	.24	.855	25.3	.767	17.0	.821	13.4	.857	5.5	.878	10.8	.894		
Tyro	Montgomery	.34	.879	14.2	.771	15.4	.828	11.5	.859	6.2	.875	12.7	.894		
Wayside	Montgomery	.37	.885	17.3	.754	14.6	.821	11.1	.862	5.3	.877	9.8	.891		
Chanute	Neosho	.31	.878	15.9	.768	17.6	.828	11.5	.864	12.9	.884	7.8	.900		
Erie	Neosho	.30	.870	21.2	.745	16.2	.823	11.9	.864	6.6	.880	5.7	.894	6.1	.906
Urbana	Neosho	.32	.876	18.8	.759	16.3	.828	4.7	.861	19.1	.877	6.0	.900		
Altoona	Wilson	.25	.865	16.2	.761	17.0	.812	11.4	.853	12.5	.872	6.7	.893		
Neodesha	Wilson	.23	.846	29.9	.741	15.0	.818	10.5	.855	11.1	.875	4.4	.894		
Yates Center	Woodson	.46	.889	7.8	.808	18.9	.838	14.6	.859	15.2	.879	6.7	.896		
KENTUCKY															
Olympia	Bath	.23	.853	11.2	.757	24.5	.804	11.5	.841	12.8	.860	6.5	.872		
Ragland	Bath	.31	.902	12.6	.767	16.0	.826	8.7	.856	11.6	.878	5.4	.898		
	Lawrence	.21	.835	33.1	.744	18.4	.818	7.7	.846	10.1	.873	6.0	.896		
Big Sinking	Lee and Estell	.14	.844	31.2	.751	17.3	.819	10.6	.849	10.8	.876	5.9	.891		
Composite from several counties		.23	.835	35.4	.735	16.2	.824	9.3	.851	9.5	.874	4.6	.894		
	Wayne	.49	.869	35.9	.751	17.3	.839	11.0	.862	10.5	.887	5.0	.898		
Cow Creek	Wolf and Estell	.13	.866	19.7	.771	16.7	.828	10.4	.855	12.6	.871	7.1	.883		
Ross Creek	Wolf, Lee and Jackson	.12	.838	35.9	.744	14.6	.826	9.7	.848	10.3	.874	5.9	.894		
Compton	Wolf	.23	.842	30.8	.747	16.7	.821	10.3	.850	10.4	.870	6.0	.882		
LOUISIANA (North)															
Elmgrove	Bossier	.27	.879	13.5	.793	18.5	.841	16.7	.858	15.8	.878	7.2	.904		
Caddo	Caddo	.25	.850	25.7	.751	18.9	.806	12.5	.841	11.7	.864	5.9	.879		

*** Lawrence, Crawford, Jasper and Cumberland.**
† Composite from Allen and other counties.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{1.55}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
LOUISIANA (North) (*Continued*)															
Caddo	Caddo	0.21	0.820	35.2	0.748	22.4	0.795	11.1	0.842	9.9	0.864	5.2	0.884		
Pine Island	Caddo	.42	.901	3.0	.828	18.3	.868	7.5	.892	17.1	.899	15.6	.907		
Homer	Claiborne	.63	.844	30.2	.736	15.5	.812	10.5	.854	11.0	.875	5.9	.892		
DeSoto, Red River and Bull Bayou.	DeSoto and Red River	.21	.822	27.6	.764	36.1	.805	11.8	.845	8.4	.868	3.7	.895		
LOUISIANA (South)															
Jennings	Acadia	.37	.911					40.5	.880	12.4	0.909–0.922	7.5	0.922–0.929	13.6	0.929–0.944
Jennings	Acadia	.36	.908					45.6	.873	14.7	.902– .921	8.1	.921– .930	8.7	.930– .944
Edgerly	Calcasieu	.68	.925					25.9	.879	15.0	.896– .914	8.0	.914– .935	14.2	.935– .972
Vinton	Calcasieu	.33	.936					22.9	.884	13.8	.913– .935	8.2	.935– .945	16.8	.945– .962
Anse La Butte	St. Martin's	.22	.919					34.8	.881	14.6	.909– .920	8.0	.920– .928	16.1	.928– .944
Anse La Butte	St. Martin's	.30	.903					34.1	.867	16.1	.896– .912	9.5	.912– .920	8.2	.920– .930
MONTANA															
Winnett	Musselshell	.36	.781	63.2	.747	25.5	.814								
NEW YORK															
	Alleghany	.10	.828	30.0	.748	17.5	.802	10.3	.838	11.3	0.854	6.3	0.873		
OHIO															
North Lima	Allen	.55	.835	31.0	.749	19.2	.815	9.9	.843	10.7	.870	5.5	.890		
South Lima	Allen, Auglaize and Mercer	.55	.842	27.0	.758	20.0	.818	10.8	.841	11.5	.869	4.9	.889		
Lima	Composite from Allen and others	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885		
Corning	Washington	.10	.838	27.8	.740	17.0	.805	9.7	.835	10.5	.854	6.3	.871		
Penn Grade	Washington	.05	.805	33.5	.739	20.2	.798	11.3	.834	11.2	.855	5.5	.868		
OKLAHOMA															
Cement	Caddo	.19	.852	20.2	.766	20.7	.809	14.0	.846	6.7	.864	13.3	.880		
Healdton	Carter	.72	.870	22.3	.753	15.8	.825	10.5	.862	6.5	.880	12.1	.897		
Hewitt	Carter	.72	.858	26.6	.737	14.3	.817	9.5	.860	4.8	.877	12.4	.899		
Walters	Cotton	.42	.859	27.7	.747	17.7	.813	10.9	.860	5.2	.877	9.3	.899		
North Bristow	Creek	.25	.824	38.8	.743	18.1	.820	10.7	.858	9.2	.880	4.6	.899		
Cushing	Creek	.28	.828	37.5	.743	18.0	.818	11.5	.855	9.6	.876	4.7	.896		
Glen	Creek and Tulsa	.30	.862	24.8	.762	17.4	.827	12.5	.860	5.2	.878	11.5	.898		
Kellyville	Creek	.28	.883	14.6	.771	15.9	.830	5.9	.861	12.1	.891	6.3	.892	5.8	0.903
Mounds	Creek	.26	.853	28.2	.750	15.8	.829	9.5	.861	11.2	.883	6.0	.899		
Slick	Creek	.44	.875	22.9	.746	13.0	.832	5.9	.856	11.4	.884	4.5	.902		
Garber	Garfield	.14	.799	52.4	.737	15.7	.816	3.9	.844	11.9	.870	2.7	.891		
Blackwell or Dilsworth	Kay	.24	.830	36.3	.748	18.0	.817	10.7	.856	9.3	.877	4.8	.898		
Newkirk or Mervine	Kay	.15	.823	35.9	.743	18.9	.815	11.2	.850	11.1	.868	4.1	.884		
Arbuckle	Marshall	.06	.794	46.2	.726	17.8	.804	9.4	.839	8.2	.858	3.4	.874		
Madill	Marshall	.06	.769	85.5	.748	10.5	.806								
Boynton	Muskogee	.15	.841	24.1	.762	19.6	.816	13.0	.850	12.4	.870	5.9	.879		
Muskogee	Muskogee	.23	.852	19.5	.762	17.8	.820	13.9	.850	12.2	.868	7.3	.883		
Billing	Noble	.16	.823	40.4	.739	17.6	.819	10.7	.858	9.6	.875	4.8	.890		
Bluff and Alluwe	Nowata	.19	.865	22.1	.763	19.5	.829	10.7	.863	13.8	.886	5.1	.906		
Delaware Extension	Nowata	.23	.859	25.3	.757	17.6	.827	13.2	.862	12.4	.886	6.1	.902		
Delaware and Lenapak	Nowata	.19	.869	19.9	.765	19.1	.826	11.4	.865	6.0	.880	11.5	.901		
Deaner	Okfuskee	.13	.826	32.1	.740	16.4	.817	11.3	.853	10.6	.876	5.9	.893		
Lyons	Okfuskee	.14	.836	28.3	.752	17.4	.816	11.5	.853	11.1	.869	6.1	.888		
Bald Hill	Okmulgee	.15	.816	37.6	.737	16.4	.817	10.5	.854	10.4	.874	4.8	.890		
Beggs	Okmulgee	.15	.830	29.9	.749	14.9	.823	6.4	.853	14.1	.876	5.5	.894		
Henryetta	Okmulgee	.13	.842	25.3	.754	18.3	.819	12.1	.854	11.1	.873	5.9	.885		
Okmulgee	Okmulgee	.13	.854	17.3	.759	17.3	.815	14.7	.849	12.8	.867	7.5	.878		
Philipsville	Okmulgee	.17	.809	39.6	.728	15.4	.817	9.0	.850	10.0	.870	4.1	.886		
Youngstown	Okmulgee	.32	.870	22.2	.760	16.0	.828	13.0	.862	4.7	.879	5.4	.890	6.8	.901
Bigheart	Osage	.19	.846	28.1	.754	19.1	.827	11.4	.862	6.6	.879	10.9	.892		
Burbank	Osage	.32	.837	29.7	.746	16.9	.822	4.7	.846	12.7	.868	10.6	.894		
Hominy	Osage	.13	.840	30.9	.745	19.1	.827	11.6	.862	6.9	.883	9.7	.893		
Osage	Osage	.23	.846	28.9	.751	18.0	.824	5.2	.858	13.1	.870	10.8	.889		
Pershing	Osage	.17	.846	26.4	.751	19.9	.825	6.4	.860	12.2	.874	5.5	.895	6.2	.903
Cleveland	Pawnee	.26	.841	30.6	.753	19.8	.821	8.3	.858	5.5	.875	10.1	.897		
Jennings	Pawnee	.33	.840	32.9	.750	18.6	.820	11.7	.855	10.2	.876	5.4	.894		
Yale or Quay	Payne	.33	.858	24.8	.756	17.8	.818	9.7	.862	10.6	.879	4.9	.897		
Allen	Pontotoc	.62	.878	22.7	.751	16.5	.826	9.7	.867	5.6	.888	14.9	.901		
Claremore	Rogers	.14	.855	23.8	.761	19.2	.822	12.0	.855	11.6	.878	6.5	.895		
Comanche	Stephens	.41	.857	26.3	.755	17.1	.820	11.0	.864	5.2	.878	10.5	.895		
Duncan	Stephens	.40	.848	31.4	.746	18.0	.815	10.4	.857	6.0	.875	11.6	.897		
Owasso	Tulsa and Rogers	.27	.851	26.9	.761	18.8	.826	12.6	.858	5.9	.875	11.1	.888		
Skiatook, Sperry and Turley	Tulsa	.23	.868	20.3	.773	18.5	.833	6.4	.864	12.8	.875	13.6	.901		
Broken Arrow	Wagoner and Tulsa	.19	.853	26.2	.764	17.8	.825	10.9	.858	11.5	.881	5.2	.896		
Wagoner	Wagoner	.15	.864	16.9	.765	17.5	.820	11.1	.852	12.4	.872	7.2	.897		
Bartlesville	Washington	.25	.871	19.0	.779	18.5	.837	7.3	.867	13.6	.881	13.2	.899		
Canary	Washington	.32	.867	20.4	.771	19.2	.830	13.5	.864	6.1	.882	12.9	.894		
Ochelata Hogshooter	Washington	.27	.864	22.0	.767	17.7	.826	6.5	.859	13.1	.875	5.1	.891	8.4	.910

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates: Light		Medium		Heavy	
		% S	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$
Pennsylvania															
	Allegheny and Wash.	0.08	0.800	37.8	0.733	20.2	0.792	9.6	0.831	9.3	0.848	5.7	0.859		
	Green	.08	.815	29.0	.745	18.7	.803	10.2	.834	11.9	.850	6.1	.865		
	McKean	.10	.823	32.5	.739	17.8	.802	9.4	.839	10.6	.853	5.7	.867		
Special Franklin Crude	Mercer	.09	.863	9.0	.824	15.1	.842	13.7	.850	13.5	.866	8.4	.876		
Composite		.08	.811	33.9	.734	19.9	.802	9.7	.835	11.1	.852	6.3	.865		
	Venango	.10	.819	29.6	.746	17.3	.806	10.9	.826	12.2	.850	5.2	.870		
	Venango	.08	.832	24.4	.761	16.4	.811	12.5	.827	12.2	.850	7.1	.870		
Texas (North)															
Holiday	Archer	.41	.839	38.2	.734	16.3	.819	11.0	.858	9.1	.885	4.9	.908		
Brownwood	Brownwood	.17	.850	24.5	.747	16.5	.821	12.5	.862	13.7	.891	5.8	.905		
Petrolia	Clay	.38	.841	34.0	.752	18.7	.818	10.9	.856	5.1	.877	5.2	.890	5.7	0.907
Santa Anna	Coleman	.16	.828	15.3	.782	18.6	.828	16.3	.852	14.6	.870	4.7	.885		
Desdemona	Comanche and Eastland	.14	.839	29.4	.761	19.4	.817	14.0	.855	5.5	.873	11.0	.893		
Ranger	Eastland	.17	.840	30.2	.759	19.7	.821	12.1	.858	12.6	.867	9.9	.895		
Mexia	Limestone	.19	.847	17.3	.768	28.4	.807	17.3	.845	12.3	.869	4.9	.894		
Corsicana	Navarro	.24	.855	19.7	.765	23.8	.811	14.7	.859	6.7	.877	11.5	.896		
Strawn	Palo Pinto	.13	.847	24.4	.763	20.2	.819	11.7	.857	12.5	.876	6.7	.890		
Moran	Shackelford	.16	.830	34.4	.743	17.2	.816	11.6	.854	10.0	.877	4.7	.897		
Breckenridge	Stepheno	.28	.844	30.0	.757	18.8	.822	11.4	.860	10.9	.880	5.0	.900		
Caddo	Stepheno	.20	.839	30.5	.756	19.1	.820	11.8	.844	11.7	.864	4.3	.885		
Burkburnett	Wichita	.38	.838	36.3	.749	17.7	.822	10.8	.862	10.4	.885	5.1	.906		
Burkburnett	Wichita	.39	.841	36.7	.742	17.0	.820	10.8	.857	5.1	.880	9.4	.899		
Electra	Wichita	.25	.824	40.8	.734	16.1	.822	8.9	.860	6.0	.876	9.0	.896		
K. M. A	Wichita	.33	.836	35.1	.746	18.1	.821	10.4	.860	5.6	.878	6.2	.895	5.4	.915
K. M. A	Wichita	.72	.854	31.2	.746	16.1	.819	9.4	.858	6.3	.880	9.6	.899		
Texhoma	Wichita	.33	.866	38.0	.739	17.2	.818	10.2	.858	5.0	.877	10.1	.897		
Thrall	Williamson	.15	.837	26.4	.763	20.8	.809	12.2	.847	11.7	.866	5.7	.880		
Young	Young	.26	.833	34.6	.750	18.7	.823	10.3	.859	5.5	.875	10.8	.892		
Texas (South)															
Somerset	Atascosa	.42	.823	38.8	.735	18.3	.812	8.4	.851	10.8	0.858–0.889	5.2	0.889–0.904		
Somerset	Atascosa	1.40	.855	31.0	.746	10.7	.818	14.6	.854	8.4	.874– .898	7.4	.898– .916		
Yturri	Bexar	0.45	.863	24.6	.752	10.8	.813	14.3	.840	11.0	.858– .883	6.6	.883– .901	2.7	0.901–0.909
Damon Mound	Brazoria	.28	.923					36.9	.886	14.9	.915– .933	8.4	.933– .939	14.1	.939– .948
Damon Mound	Brazoria	.36	.921	5.8	.818			36.5	.874	16.4	.913– .933	6.0	.933– .940	17.5	.940– .965
West Columbia	Brazoria	.29	.934					27.0	.851	13.8	.917– .933	8.2	.933– .943	20.7	.943– .958
West Columbia	Brazoria	.21	.906					48.8	.878	10.4	.911– .916	13.2	.916– .923	8.0	.923– .927
West Columbia	Brazoria	.45	.940					28.6	.886	12.0	.918– .934	7.5	.934– .945	15.9	.945– .957
Barbers Hill	Chambers	.67	.858	31.0	.757	5.5	.825	18.6	.854	8.0	.885– .906	4.7	.906– .912	5.9	.912– .918
Pierdes-Pintos	Duvall	.55	.927					33.9	.870	10.8	.894– .919	9.4	.919– .948	21.9	.948– .960
Blue Ridge	Fort Bend	.45	.944					21.8	.883	11.4	.922– .937	7.6	.937– .947	18.1	.947– .968
Blue Ridge	Fort Bend	.39	.894	16.2	.784			23.7	.867	12.7	.896– .909	5.9	.909– .927	11.2	.927– .960
Batson	Hardin	.61	.903	8.2	.789			34.9	.876	11.4	.908– .920	8.2	.920– .928	8.1	.928– .939
Saratoga	Hardin	.57	.977					16.8	.883	9.0	.919– .934	8.6	.934– .950	15.3	.950– .977
Sour Lake	Hardin	.43	.884	16.7	.765			30.6	.874	10.6	.907– .927	6.0	.927– .932	9.4	.932– .939
Goose Creek	Harris	.22	.926					28.5	.887	14.2	.911– .926	8.3	.926– .935	15.3	.935– .952
Goose Creek	Harris	.20	.917					36.0	.882	14.2	.914– .924	7.4	.924– .930	14.7	.930– .943
Goose Creek	Harris	.21	.910					39.2	.876	13.7	.909– .919	7.5	.919– .928	11.2	.928– .961
Goose Creek	Harris	.55	.897					51.7	.872	13.2	.900– .915	7.4	.915– .927	7.1	.927– .943
Goose Creek	Harris	.49	.931					31.0	.886	9.3	.915– .926	7.3	.926– .935	18.2	.935– .956
Humble	Harris	.43	.938					24.8	.885	3.2	.912– .918	20.0	.918– .947	17.1	.947– .961
Humble	Harris	2.40	.948	3.7	.823			24.9	.882	14.4	.913– .931	7.7	.931– .942	10.6	.942– .962
Pierce Junction	Harris	0.29	.921					36.2	.880	16.4	.922– .940	5.8	.940– .946	13.8	.946– .963
Spindle Top	Jefferson	2.31	.936					28.5	.880	13.8	.910– .925	8.6	.925– .937	17.8	.937– .955
Hull	Liberty	0.35	.863	26.6	.762			27.3	.858	10.4	.886– .905	7.0	.905– .918	7.7	.918– .932
Hull	Liberty	.44	.926	3.8	.800			22.0	.871	11.1	.901– .916	6.6	.916– .924	15.6	.924– .945
North Dayton	Liberty	.50	.899	9.8	.796			45.5	.884	11.8	.924– .937	7.2	.937– .939	8.6	.939– .942
Markham	Matagorda	.18	.831	50.2	.782	9.3	.809	26.5	.850						
Nacogdoches	Nacogdoches	.39	.923					19.5	.877	14.9	.891– .905	12.6	.905– .915	8.8	.915– .921
Orange	Orange	.45	.912					31.9	.869	13.6	.896– .911	9.7	.911– .926	8.0	.926– .930
Terry	Orange	.34	.881					27.0	.880	13.6	.901– .920	7.2	.920– .928	16.0	.928– .939
Mirando	Zapata	.25	.923					49.8	.893	14.0	.915– .931	4.5	.931– .941	14.8	.941– .969
West Virginia															
Maryland Grade	Hancock	.084	.783	45.9	.718	16.5	.794	8.4	.839	8.3	0.848	4.3	0.858		
Maryland Grade	Harrison and Doddridge	.20	.808	29.5	.741	18.9	.795	9.0	.823	11.5	.840	7.2	.859		
Maryland Grade	Harrison and others	.27	.800	33.4	.735	20.4	.795	9.8	.823	12.1	.843	4.0	.864		
Blue Creek	Kanawha	.11	.810	40.2	.727	18.0	.797	9.2	.829	9.1	.849	4.6	.862		
Cabin Creek	Kanawha	.19	.797	40.5	.730	21.0	.797	8.0	.827	8.9	.844	4.2	.856		
Kelly Creek	Kanawha	.11	.799	39.6	.731	18.4	.798	9.9	.829	9.8	.847	4.5	.859		
Eureka Grade	*	.10	.805	31.3	.739	18.5	.799	12.1	.825	11.0	.844	5.6	.856		
Eureka Grade	*	.24	.806	37.7	.734	17.7	.801	9.2	.829	9.6	.845	6.0	.848		

* Ritchie, Wood, Wirt, Calhoun, Roan and Kanawha.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates: Light		Lubricating distillates: Medium		Lubricating distillates: Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
WEST VIRGINIA (*Continued*)															
Maryland Grade	*	0.28	0.805	38.3		18.0	0.804	9.3	0.825	9.3	0.852	5.2	0.872		
Maryland Grade	Tyler	.095	.804	35.8	0.744	20.8	.795	10.6	.824	11.2	.844	4.8	.862		
Eureka Grade	Tyler, Doddridge, and Wetzel	.098	.808	34.0	.748	19.4	.810	9.9	.828	10.3	.844	5.3	.857		
Maryland Grade	Tyler, Doddridge, and Wetzel	.094	.803	37.1	.737	18.7	.798	10.1	.827	9.8	.839	4.8	.852		
Maryland Grade	Wetzel and Marshall	.11	.804	34.6	.732	19.1	.798	10.7	.827	10.0	.846	5.1	.862		
WYOMING															
Greybull	Bighorn	.08	.803	38.6	.738	17.8	.806	11.0	.830	10.9	.844	4.7	.858		
Ferris	Carbon	.19	.842	31.1	.747	13.4	.823	10.8	.847	11.7	.864	6.0	.881		
Lost Soldier	Carbon	.11	.875	16.7	.804	18.5	.854	18.6	.864	15.7	.875	6.7	.898		
Rock Creek	Carbon	.27	.843	31.4	.744	14.2	.826	10.0	.854	10.3	.876	5.4	.890		
Big Muddy	Converse	.17	.863	22.2	.762	15.7	.832	9.0	.860	11.1	.877	5.9	.890		
Dallas	Fremont	2.42	.914	12.8	.772	14.5	.827	10.8	.873	7.5	.897	7.0	.916	7.2	0.935
Lander	Fremont	2.62	.913	11.0	.755	16.0	.825	11.1	.869	15.1	.899	6.1	.921		
Maverick	Fremont	2.46	.922	8.6	.765	14.7	.824	10.9	.869	13.7	.901	8.0	.924		
Pilot Butte	Fremont	0.22	.848	24.0	.765	19.7	.815	13.2	.846	12.8	.864	5.9	.884		
Plunkett	Fremont	.55	.846	21.0	.779	22.6	.827	16.3	.852	14.0	.868	6.5	.883		
Grass Creek	Hot Springs	.14	.809	42.6	.741	20.0	.820	9.9	.850	9.3	.865	4.5	.881		
Hamilton Dome	Hot Springs	2.09	.903	17.6	.746	15.8	.826	8.7	.876	5.7	.893	12.4	.917		
Pine Mountain	Natrona	0.51	.953	Decomposed when heated at atmospheric pressure											
Salt Creek	Natrona	.18	.841	29.3	.750	15.7	.824	10.8	.847	11.1	.865	5.8	.880		
Shannon	Natrona	.20	.909	3.1	.838	11.1	.867	4.9	.884	19.1	.892	8.0	.905	8.4	.909
Lance Creek	Niobrara	.18	.823	33.5	.754	16.2	.812	11.3	.849	10.7	.859	6.0	.876		
Mule Creek	Niobrara	.14	.867	11.7	.768	17.4	.821	13.1	.850	14.6	.869	7.4	.882		
Elk Basin	Park	.14	.827	40.5	.748	17.4	.829	10.6	.862	9.8	.875	4.8	.890		
New Castle	Weston	.15	.840	31.6	.754	17.4	.826	10.3	.856	11.0	.871	5.6	.887		
Osage Range	Weston	.29	.837	34.8	.746	15.8	.825	9.8	.857	10.5	.873	5.1	.893		

* Ritchie, Wood, Wirt, Calhoun, Roan, Kanawha and Gilmer.

SPECIFIC GRAVITY AND THERMAL EXPANSION

In this section, S will be used to represent $d_{15.56}^{15.56°}\text{C} = d_{60}^{60°}\text{F}$.

Conversion Formulae

All weights in vacuo

$$°\text{API} = \frac{141.5}{S} - 131.5. \quad °\text{Bé (American)} = \frac{140}{S} - 130$$

$$\text{Lb. per gal. (U. S.)} = 8.328 \times S$$
$$\text{Lb. per gal. (Brit.)} = 10.00 \times S$$
$$\text{Gal. (U. S.) per lb.} = 0.1201 \times S$$
$$\text{Gal. (Brit.) per lb.} = 0.1000 \times S$$

For other conversion factors, *v.* vol. I, p. 23. For elaborate computed conversion tables convenient for interpolation, *v.* (10).

Crude Petroleums

The specific gravity of crudes varies with locality between the extreme limits 0.65 to 1.07. Below are given only those crudes for which values above 0.95 or below 0.75 have been recorded. The recorded data for all other crudes lie between the above values. For these *v.* (26, 39, 53.1, 87, 120, 169).

Specific Gravity of Crude Petroleum from Various Parts of the World

Sp. gr. > 0.95

Source	Sp. gr.
AFRICA	
Algeria	0.79 to 0.98
Egypt	0.83 to 0.97
Gold Coast	0.87 to 0.98
Ivory Coast	0.96
Sidi Brahim	**1.02**
Tunis	0.97
ASIA	
Assam	0.86 to 0.98
Burma	0.81 to 1.00
Japan	0.80 to 0.98
Malay Archipelago	
Borneo	0.86 to 0.97

Specific Gravity of Crude Petroleum.—(*Continued*)

Source	Sp. gr.
Java	0.81 to 0.97
Roengkoet	0.97
Persia	0.78 to 1.06
AUSTRALIA	0.84 to 0.97
New Zealand	0.84 to 0.97
EUROPE	
Galicia (Drohobycz)	0.84 to 0.96
Germany	0.81 to 1.00
Greece	1.05
Hungary	0.80 to 0.98
Italy	0.75 to 0.97
Russia (Daghestan)	0.85 to 0.96
NORTH AMERICA	
Canada	0.75 to 0.97
Cuba	0.73 to 0.96
Haiti	0.92 to 0.96
Mexico	0.79 to 1.06
United States	
Alaska	0.79 to 0.99
California	0.77 to 1.01
Louisiana	0.80 to 0.97
Oklahoma	0.79 to 0.88
Texas	0.80 to 0.97
Utah	0.83 to 0.95
Wyoming	0.80 to 1.00
SOUTH AMERICA	
Argentina	0.90 to 1.00
Barbados	0.88 to 0.97
Colombia	0.86 to 0.97
Ecuador	0.88 to 0.99
Peru	0.82 to 0.95
Trinidad	0.81 to 0.98

Specific Gravity of Crude Petroleum.—(*Continued*)

Source	Sp. gr.
Sp. gr. < 0.75	
Europe	
Italy	0.75 to 0.97
Russia (Caucasus)	**0.65**
North America	
Canada	0.75 to 0.97
Cuba	0.73 to 0.96
United States	
Pennsylvania	0.70 to 0.89

Straight Run Petroleum Products [113]

Approximate specific gravity range at 15.5°C = 60°F

Product	Range
Paraffin-base Crude	
Cymogene (rare)	0.588
Light petroleum ether	0.633–0.626
Heavy petroleum ether	0.654–0.639
Natural gas gasolene	0.675–0.622
Gasolene	0.747–0.709
Kerosene	0.816–0.797

Straight Run Petroleum Products [113].—(*Continued*)

Product	Range
Mineral seal oil (300 burning oil)	0.825–0.811
Gas oil	0.845–0.816
Non-viscous neutrals	0.865–0.850
Viscous neutrals	0.882–0.865
Paraffin oils	0.904–0.876
Paraffin wax	0.947–0.871
Red oils	0.910–0.904
Filtered cylinder stock	0.896–0.887
Bright stock	0.916–0.893
Steam-refined oils	0.928–0.898
Naphthene-base Crude	
Natural gas gasolene	0.702–0.669
Light gasolene (if any)	0.720–0.702
Gasolene (if any)	0.763–0.731
Kerosene (if any)	0.825–0.816
Gas oil	0.876–0.855
Low pour test machine oil (low viscosity)	0.928–0.922
Low pour test machine oil (medium viscosity)	0.934–0.928
Low pour test machine oil (high viscosity)	0.940–0.934
Black oil	0.947–0.940
Flux	0.986–0.973

Gasolene Fractions [177]

Kind of gasolene	Sp. gr. of fraction. 15.5°/15.5°C = 60°/60°F						
	Fractionation temperatures						
	Up to 50°C	50° to 75°C	75° to 100°C	100° to 125°C	125° to 150°C	150° to 175°C	175° to 200°C
Eastern "straight" refinery	0.633 to 0.639	0.666 to 0.672	0.699 to 0.712	0.727 to 0.736	0.742 to 0.755	0.764 to 0.770	
Mid-Continent "straight" refinery	0.630 to 0.645	0.672 to 0.696	0.712 to 0.736	0.736 to 0.761	0.755 to 0.779	0.773 to 0.779	0.788 to 0.795
California "straight" refinery	0.639 to 0.645	0.678 to 0.693	0.723 to 0.739	0.752 to 0.764	0.773 to 0.788		
Blended casing head (eastern)	0.624 to 0.633	0.663 to 0.675	0.703 to 0.715	0.733 to 0.739	0.752 to 0.761	0.767 to 0.776	0.782 to 0.785
Cracked (Mid-Continent)	0.636 to 0.645	0.675 to 0.684	0.712 to 0.721	0.736 to 0.749	0.752 to 0.767	0.767 to 0.785	0.788 to 0.801

Blending Chart.—For use in determining % of naphtha to be added to gasolene to obtain blend of given density, *v.* [8].

Lubricating Oil at Low Temperatures

This sample had the following properties: $S_{15.5}^{15.5} = 0.9427$; Fl. P., 224°C; η at 98.9°C, 92 sec Saybolt; Pour point, −18°C. The density data were $d_4^t = 0.9740$, (−35° to −40°C); and $d_4^t = 0.9523 - 0.000665t$, (−30° to +20°C) [76].

Paraffins

Solid.—$d_{15}^{15} = 0.87 - 0.94$; $d_{15}^{50} = 0.84 - 0.89$. Recorded data on thermal expansion very conflicting, possibly due to enclosed air [19, 158, 166, 211]. Between −190° and 17°C Dewar found $\frac{1}{V}\frac{\Delta V}{\Delta t} = 0.000357$ per deg [43].

Liquid.—$d_{15}^{50} = 0.777 - 0.785$; $d_{15}^{80} = 0.755 - 0.780$. $d_{15}^{t} =$ const. (= 53 to 85) $\times 10^{-5}t$ (between *ca.* 50° and 100°C) [19, 158, 166, 211].

Miscellaneous

Petrolatum ("*Vaseline*").—$d_4^t = 0.873$, 23°; 0.868, 32°; 0.862, 42°C [206].

Petroleum Ether.—$V_t = V_0(1 + 146 \times 10^{-5}t + 16.0 \times 10^{-7}t^2)$, −190° to 0°C [90].

Thermal Expansion

$$d_t = d_s - \alpha(t - t_s) + \beta(t - t_s)^2$$
$$\alpha = (66 \pm 5) \times 10^{-5};\ \text{for } S \not< 0.84$$
$$\alpha = [(189.4 - 146.5S) \pm 3] \times 10^{-5};\ \text{for } S \not> 0.84$$
$$\beta = [(-15.4 + 19S) \pm 2] \times 10^{-7}$$
$$d_t = d_4^t \text{ or } d_{15.5}^t$$
$$d_s = d_4^{t_s} \text{ resp. } d_{15.5}^{t_s} \text{ when } 15° < t_s < 35°$$

S = the density or specific gravity (two decimal places sufficient) at any temperature between *ca.* 15° and 35°.

Example: Given $d_{15.5}^{17} = 0.6935$, to find $d_{15.5}^{60}$

$d_{60} = 0.6935 - (189.4 - 146.5 \times 0.69) \times 10^{-5} \times (60 - 17) + (-15.4 + 19 \times 0.69) \times 10^{-7}(60 - 17)^2 = 0.6551 \pm$ *ca.* 0.0003.

For all practical purposes, the above relations appear to be applicable to all petroleum oils, both crude and refined, between 0° and 50°C (and probably to 100°C) as long as they continue to remain homogeneous liquids sufficiently fluid to be measured with a hydrometer [18]. For elaborate computed tables convenient for temperature conversions and based substantially on the above relations *v.* [10, 41].

Additional Literature on Thermal Expansion.—Crudes [51, 94, 148, 182, 183, 197]. Derivatives [94, 102, 117, 181].

Expansion above 100°*C.*—A recent investigation [225] of California petroleum products yields the equations:

$$v_t = v_{15.56}[1 + \alpha(t - 15.56°) + \beta(t - 15.56°)^2] \quad \text{(Range, 15° to 260°C)}$$

and

$$v_t = v_{260}[1 + \alpha'(t - 260°) + \beta'(t - 260°)^2] \quad \text{(Range, 260° to 400°C)}$$
$$\alpha = [2.32 - 1.7S] \times 10^{-3};\ \text{for } S \not< 0.82$$
$$\alpha = [4.36 - 4.2S] \times 10^{-3};\ \text{for } 0.82 < S < 0.75$$
$$\beta = [4.86 - 4.5S] \times 10^{-6}$$

For S =	1.0	0.95	0.90	0.89
$10^3\alpha'$ =	0.75	0.83	1.05	1.20

$$\beta' = [20.29 - 19.45\,S] \times 10^{-6}$$

where v_t is the volume (cm^3) at t°C, and S is the specific gravity at 15°C.

COMPRESSIBILITY

The mean coefficient of compressibility between P_1 and P_2 is defined by the equation

$$\beta = \frac{V_{P_1} - V_{P_2}}{V_{P_1}(P_2 - P_1)}$$

Kerosene and Lubricating Oils.—Within the accuracy of the measurements, all available data are correctly expressed by the equation

$$\frac{10^{-6}}{\beta} = \mathrm{a} + \mathrm{b}P - \mathrm{c}P^2 + \mathrm{d}P^3,$$

in which $\beta = \dfrac{V_0 - V_P}{V_0 P}$ is the mean coefficient between 0 and P.

Conversion Factors.—To convert a pressure, in any of the following units, into atmospheres, multiply it by the factor given.

Megabarye	kg cm^{-2}	Lb. in. $^{-2}$
0.98692	0.96784	0.068047

Kerosene.—Between 1 and 11 atmospheres and 0–100°C, β in atm.$^{-1}$ is expressed by the equation $\beta = (67.5 + 0.458t) \times 10^{-6}$ (161).

Paraffin (17)

M. P. 55°C $\quad \beta = \dfrac{V_{20} - V_P}{V_{20}P}$

P	$10^6\,\beta$ at t°C			
atm.	64°	100°	185°	310°
20				
100	83	106	172	331
200	83	103	156	289
300	84	99	147	257
400	solid	94	137	236

P in atmospheres. "Range" = pressure limits within which the equation may be used to calculate $\dfrac{V_{P_1} - V_{P_2}}{V_{P_1}}$

Name of oil	t°C	10^3a	10^6b	10^{12}c	10^{15}d	Range atmospheres	$\dfrac{10^5(V_0 - V_{1000})}{V_0 \times 1000}$	Lit.
Kerosene	20	(13.05)	4.417$_5$	160.2$_4$	5.11$_4$	2000–12 000	5.776	(1)
Kerosene	20	13.05	4.205$_9$	135.9$_4$	3.68$_7$	0–12 000	5.839	(23)
Kerosene	40	11.60	4.222$_0$	135.3$_9$	3.34$_8$	0–12 000	6.374	(23)
Kerosene	60	10.48	4.037$_9$	113.6$_9$	2.48$_4$	0–12 000	6.941	(23)
Kerosene	80	9.55	3.807$_9$	91.1$_5$	1.79$_4$	0–12 000	7.537	(23)
"Paraffin oil"*	34	12.0	4.631	280.6	24.3	0– 4 300	6.107	(153)
Lubricating oils								
"F. F. F. cylinder"	40	17.7	4.3	0.0	0.0	0– 1 400	4.545	(95.1)
"Mobile A"	40	17.4	4.3	0.0	0.0	0– 1 400	4.608	(95.1)
"Mobile BB"	40	18.0	4.3	0.0	0.0	0– 1 400	4.484	(95.1)
"Victory red"	40	18.9	5.0	0.0	0.0	0– 1 400	4.184	(95.1)
"Bayonne"	40	17.$_1$	4.3	0.0	0.0	0– 1 500	4.673	(95.1)

* $d_4^0 = 0.812$; $d_4^{34} = 0.78_6$; flash point 55°C.

VISCOSITY

See also Lubricants and Lubrication, p. 164.

Viscosity Units and Their Interconversion. *See* vol. I, p. 25.

Viscosity at Room Temperatures.—Typical values in poises are:

(*a*) Gasolenes, 0.003–0.006;
(*b*) Kerosene, 0.02;
(*c*) Light lubricating oils, 0.025–1.5;
(*d*) Medium lubricating oils, 1.5–3.5;
(*e*) Heavy lubricating oils, 3.5–20;
(*f*) Petrolatum (M. P., 85°–95°F), 1.3 at 130°, 0.24 at 210°F.

Variation of Viscosity with Temperature.—If the viscosity of an oil is known at two temperatures, its viscosity at a third temperature may be obtained graphically with the aid of Fig. 1. When the viscosity temperature values for any oil are graphed on this chart a straight line will be obtained for all portions of the temperature range within which the oil remains a homogeneous liquid of constant composition (11). Copies of this chart may be obtained by addressing The Texas Company, New York City.

SURFACE TENSION

Below are summarized the reported data on the surface tension (γ, in dynes per cm) of various products.

Crudes.—24–38 at 20°C (63, 84, 160, 176). The lower values, 24–26, are reported for crudes from Pennsylvania and California (176); the higher values, 35–38, for crudes from California fields at Montebello, Sunset, and Kern (84).

Petroleum Distillates.—For distillates up to 300°C, γ = 19–29 at 20° and is approximately a linear function of the density. *See* Fig. 12 (p. 157). $d\gamma/dt = ca.\ -0.1$ per °C between 0° and 50° (63, 64, 140, 176).

Naphthas.—(B. P. up to 150°C). γ = 19–23 at 20° (176).

Kerosenes.—(B. P. 150°–300°C). γ = 23–32 at 20° (77, 176).

Gas Oils.—γ = 28–29 (175).

"*Gas Oil Distillates.*"—(150°–300°C). γ = 21–28 (175).

"*Tar Oils.*"—γ = 34–37.6 (175).

"*Tar Oil Distillates.*"—(150°–300°C). γ = 27–36 (175).

Lubricating Oils.—Oklahoma and California. γ = 36–37.5 at 30°C (63, 78).

"*Wax Distillates.*"—γ = 34–36 at 30°C (63).

Paraffin.—γ = 30.6 at 54°C (162).

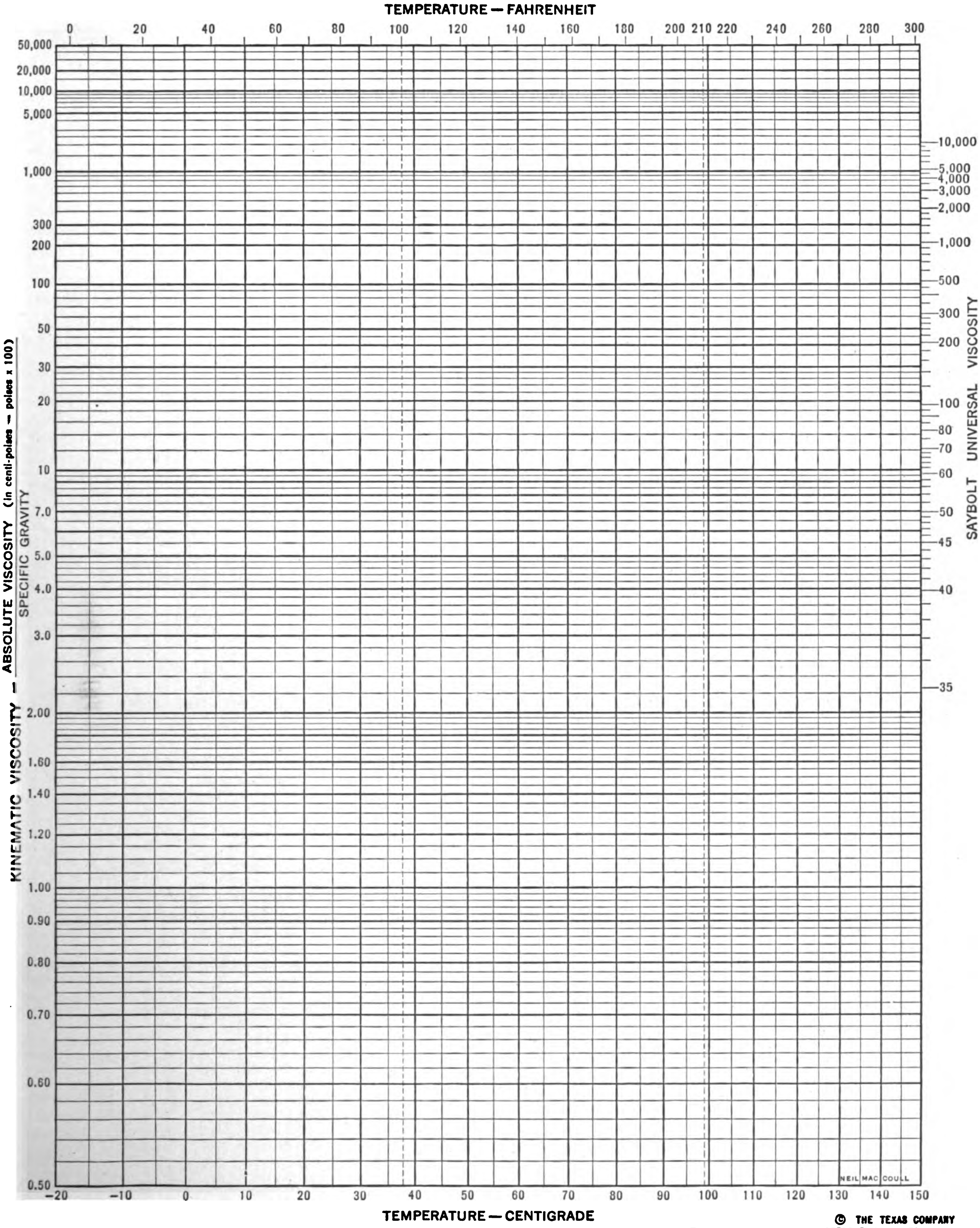
INTERFACIAL TENSIONS

Oil-Water Interface.—Dyne cm^{-1}. Gasolenes and naphthas, 39–51: kerosene, 47–49: mineral seal, 47–50: lubricating oils, 33–54: cylinder oils, petrolatum, paraffin at higher temperatures, 35–50, increasing after filtration. Several days' exposure to light produces decreases up to 30% (70, 99). $d\gamma/dt = ca.\ -0.1$ between 4° and 8°C.

Addition of fatty acids lowers the interfacial tension against both H_2O and Hg (20, 213).

PENETRATIVITY (1)

The penetrativity, z, of a liquid is measured by the ratio $\gamma/2\eta$ where η is the viscosity (206). If z for H_2O is taken as 1 at room temperature, z for kerosene is 0.05 at 20°C; z for paraffin is 0.092 at 65°, 0.39 at 185° and 0.45 at 215°C. z for petrolatum ("vaseline") in absolute units is $0.063(t - 30)^2$ cm sec^{-1}, where t is the temperature in °C between 100 and 200.



VISCOSITY—TEMPERATURE CHART

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PETROLEUM AND ITS PRODUCTS

Fig. 1.

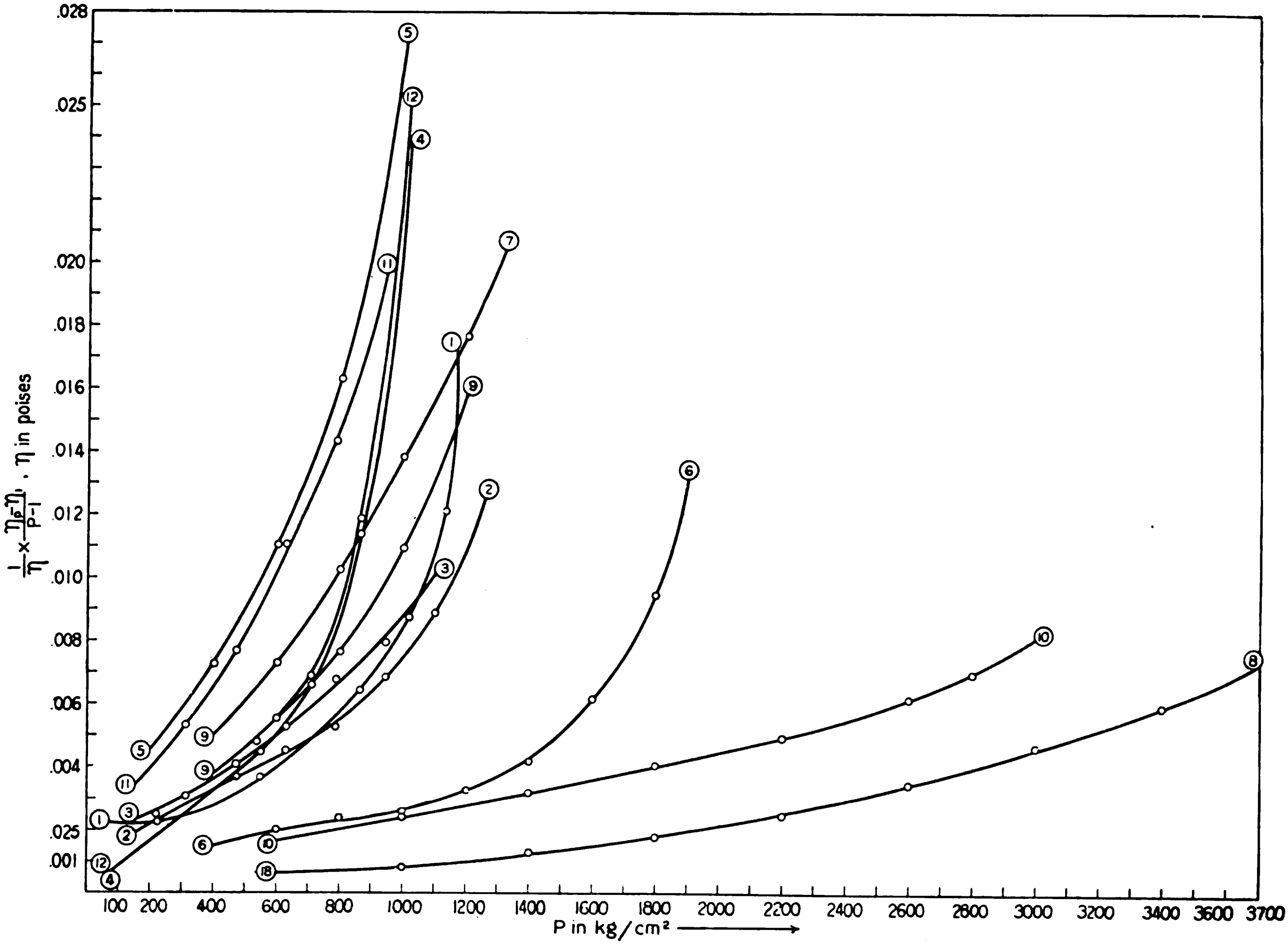

FIG. 2.—Variation of viscosity with pressure.

Curve No.	Designation of oil	t, °C	Lit.
1	Mobiloil "A"	40	(95)
2	Bayonne: d^{15}_{15} 0.906; Fl. P. 191°C; η_{100} 330 Saybolt; pour test 0°C		(95)
3	F. F. F. cylinder: d^{15}_{15} 0.892; Fl. P. 260.0°C; η_{100} 2400 Saybolt; pour test 5.6°C	40	(95)
4	Mobiloil "B. B."	40	(95)
5	Mobiloil "A"	24	(85)
6	Mobiloil "A"	100	(85)
7	Texaco	24	(85)
8	Texaco	100	(85)
9	Veedol	22	(85)
10	Veedol	100	(85)
11	Victory red mineral: d^{15}_{15} 0.914; Fl. P. 183.9°C; η_{100} 1140 Saybolt; pour test 2.8°C	40	(95)
12	Mobiloil "B": d^{15}_{15} 0.908; Fl. P. 201.7°C; η_{100} 390 Saybolt	40	(95)

MELTING POINT

The petroleum products of commerce are all mixtures, and consequently possess no sharp melting or freezing point; but exhibit instead a *melting range*. It is, of course, possible by suitable blending to obtain a product with almost any initial melting or freezing point between the extreme limits of −150°C (0.70 specific gravity gasolene) and +60°C (the high melting waxes).

Typical Values.—The limiting values recorded below show the regions of the temperature scale within which the melting or freezing ranges of some typical commercial products may be expected to lie (For "pour test" *see* p. 156).

Material	Typical melting or freezing range, °C
Gasolene 0.704 sp. gr. 15.5/15.5	−122 to −150
.719 sp. gr. 15.5/15.5	−120 to −147
Petroleum jelly—pale	39 to 51
Paraffin waxes:	
Match wax	40.5 to 46
White crude scale (Pa.)	50 to 52.2
Semi-refined (Pa.)	50 to 51
Fully refined (Pa.)	49 to 50
Fully refined (Calif.)	59 to 60
Ceresins:	
General range	60 to 80
Normal wax	65 to 66
Pure	79 to 80

Melting Point of Paraffins

Variation of melting point with oil content (221)

Material	% of pressed oil	Refractive index at 25°C	Melting point °C
"Parowax"	0.16	1.4481	51.7
Refined wax	0.28	1.4487	50.0
Refined wax	0.25	1.4485	50.0
Refined wax	0.17	1.4481	51.7
Refined wax	0.16	1.4479	51.7
Refined wax	0.09	1.4476	54.4
Refined wax	0.08	1.4475	54.4
Scale wax	2.58	1.4570	48.3
Scale wax	2.56	1.4568	48.3

Variation of Melting Point of Paraffin with Pressure

$t_P = t_0 + 0.029776 \quad (P - 1) - 0.0000523 \quad (P - 1)^2$, between 1 and 200 atm.

t_P (resp. t_0) = melting point of paraffin under pressure P (resp. 1 atm.).

SOLUBILITY OF PARAFFIN

For solubility of various kinds of paraffin in gasolenes, kerosene, lubricating oil, paraffin oil, fuel oil, benzene, alcohols, and acetic acid *see* (184).

VAPOR PRESSURE AND BOILING POINTS

The few available data when graphed (log p against $1/T$) are found empirically to give approximately straight lines. p = the vapor pressures at T°K. In the table below are given, (1) typical or limiting values of the B. P. (at 1 atm.) for the class, (or, in parentheses, the B. P. at 1 atm. as obtained by extrapolation of the vapor pressure curve); (2) the range covered by the available vapor pressure data; (3) the value of d $\log_{10} p/d(1/T)$, the slope of the vapor pressure curve; and (4) the source of the experimental data.

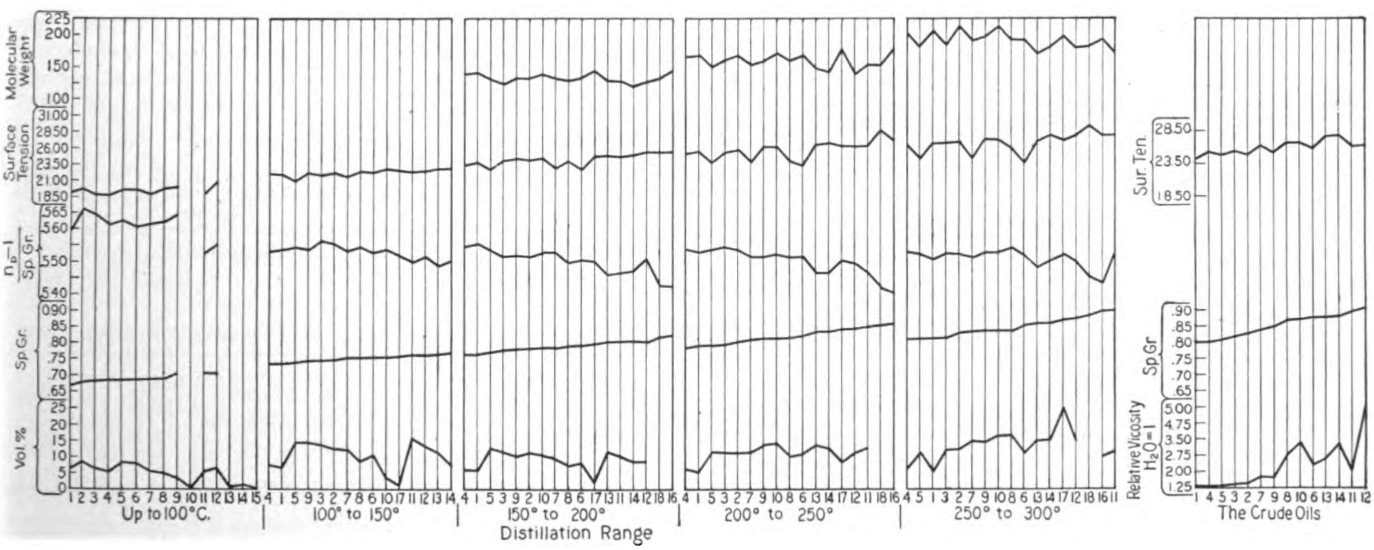

Fig. 3.—Comparison of the physical properties of petroleum distillates from different crudes (176).

Source of Crude Petroleums Used

1. Pa., Brandon, Pleasantville (580 ft.).
2. Okla., Collinsville.
3. Pa., Emlinton (1050 ft.).
4. Pa., Emlinton (1195 ft.).
5. Pa., Brandon, Pleasantville (550 ft.).
6. Calif., Piru Ventura Co.
7, 9, 10. Okla., Collinsville.
8. Okla., Healdton.
11. Calif., Piru, Ventura Co.
12. Calif., Santa Maria.
13, 14. Russia.
15, 16, 18. Calif., Midway, Kern Co.
17. Mexico.

Vapor Pressure Data—Petroleum Products

Designation of material	No. of samples	Normal B. P. °C	Pressure range mm Hg	$\frac{d \log_{10} p}{d(1/T)}$	Lit.
Gasolenes	6	93–198	30– 2 500	1600–1700	(25, 35, 45, 61, 171, 217, 218, 219)
Kerosene	1	215–255	50– 630	2230	(218, 219)
Kerosene	1	(240)	1800–30 000	3100	(42)
Gasolene	1	(63)	1800–30 000	1160	(42)
Paraffin-base oil	1	(315)	10– 100	1240	(222)
Transformer oil	1	200	300– 700	740	(33)
Vaseline	1	(215)	2000–16 000	2950	(42)
C_6H_6	1	80.5	160–40 000	1670	(44, 115, 217)
n-$C_{20}H_{42}$	1	330	130– 8 000	3600	(217)
Kerosene W. W	1	125	250– 3 000	860	(33)
Casinghead gasolene	1	(48)	1000–13 000	1130	(33)
Gasolene	1	(81)	1000– 6 400	1320	(33)

See also (200, 215, 220).

Correction of B. P. for Barometric Pressure.—In the present state of our knowledge, it is necessary to know the slope of the log p, $1/T$ curve for the particular type of product under examination (*i.e.*, the B. P. must be determined at two pressures), in order to be able to make this correction with any degree of certainty for pressures not close to 760 mm.

DEW POINTS

Definitions and Abbreviations.—The temperature at which condensation begins, when a mixture of air and motor fuel is cooled, is called the *dew point*, t_D. The *dew-point index*, I_D, is the sum of the °C boiling points at the 10, 20, 50, 70, 90, and 100% points of the 100 cc standard Engler distillation procedure. For °F it is one-half this sum. The 85% *point*, t_{85}, is the boiling point corresponding to the 85% point of the Engler distillation.

The following generalizations have been put forward.

Thirteen commercial gasolenes with I_D values ranging from 612 to 1025 give, when mixed with 15 parts of air by weight, values of t_D ranging from 10° to 88°C, the relation being

$$t_D = [12 + 0.187\ (I_D - 600)] \pm ca.\ 5°C$$ (79, 80, 218).

Thirteen commercial gasolenes with t_{85} values ranging from 115° to 210°C give values of t_D ranging from 10° to 88°C, the relation being

$$t_D = [10 + 0.83\ (t_{85} - 115)] \pm ca.\ 5° \text{ to } 10°C$$ (79, 80, 218).

An increase in the ratio of air to fuel lowers the t_D (79, 80). *See* Fig. 4. According to Stevenson and Stark (193) the dew point of any gasolene-air mixture may be accurately (±2°C) obtained from the chart of Fig. 5. This chart is based upon the Deppé end point for the particular gasolene under examination. For method of determining this end point, *v.* (193).

For another method requiring the determination of three empirical constants of the gasolene, *v.* (103).

FLASH POINT

Definition.—The *Flash point* (Fl. P.) of a liquid is an arbitrary ignition temperature of its saturated vapor. Its value depends very materially upon the apparatus and experimental procedure employed, as illustrated by the following tables:

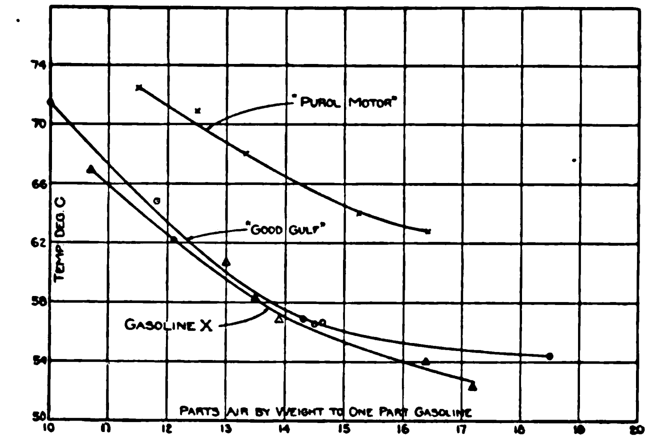

Fig. 4.—(*Courtesy Industrial and Engineering Chemistry.*)

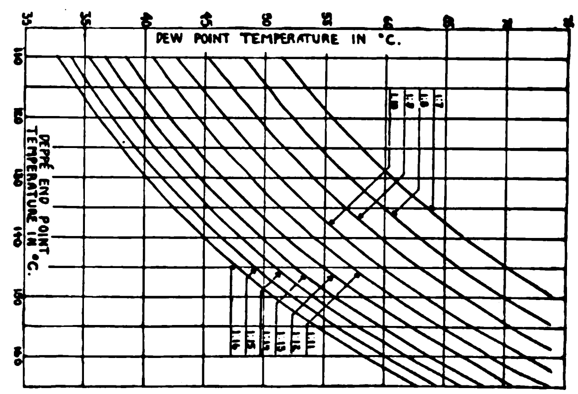

Fig. 5.—(*Courtesy Industrial and Engineering Chemistry.*)

The ratios for the curves are parts gasolene to parts air by weight.

Comparison of Flash Tests by Different Instruments

Type of oil (2)	Sp. gr.	°C Treu-mann	°C Al-brecht	°C Pen-sky
Russian spindle	0 890	171.5	164.5	151
Russian machine	.908	211	199.6	193
Mixture of the above	.896	180.5	180	159
Wagon oil	.910	181	173.5	160
Locomotive oil	.912	185	182	170
Heavy machine oil	.916	236	207	202
Russian cylinder	.916		265	256

Type of oil (30)	Pensky Martens, °C	Open cup, °C
Mexican crude oil	19.0	35.0
Pechelbronn gas oil	26.2	34.0
Motor petrol	26.5	33.5
Diesel motor oil	58.0	82.0
Dried Pechelbronn crude	60.0	72.0
Motor oil	84.0	97.5
Cracking gas oil	85.0	95.0
Diesel motor oil	89.0	90.0
Tar oil	87.0	92.5
Residue	98.5	119.5
Heavy oil	101.0	110.0
Vaseline oil	175.0	177.0
Galician Diesel motor	128.0	177.0

Typical Values.—*See* Fig. 6.

Comparison of Flash Tests by Different Instruments

Material (39)	Abel, °C	Tagliabue closed, °C	Elliot, °C	Pensky Martens, °C	Cleveland open, °C	Luchaire (French), °C
Naphtha	30.0	33.3	33.3	35.0	37.8	37.8
Naphtha	34.4	39.4	36.7	40.6	46.1	50.0
Water-white kerosene	52.8	54.4	53.3	57.2	60.0	58.9
Petrolite	61.1	59.4	60.0	65.6	68.3	62.2
Gas oil				90.6	93.3	92.2
300 oil				123.9	129.4	130.0
Straw oil				157.2	162.8	161.1
Ice machine oil				204.4	196.1	205.6
Engine oil				221.1	226.7	221.1
Cylinder oil				262.8	273.9	263.9
Heavy cylinder oil				265.6	293.3	265.5

Apparatus (53,1)	Kerosene, °C A	Kerosene, °C B	Kerosene, °C C
Engler and Haass	22	29	40
Tagliabue open	31	42	52
Danish open	21	30	43
Saybolt open	31	36	51
Tagliabue closed	32		
Abel closed	17	23	33
Parish closed	21	27	38

Variation with Barometric Pressure.—If the logarithm of the barometric pressure is graphed against $1/T_{Fl}$ where T_{Fl} is the absolute temperature of the Fl. P., a straight line is obtained, which apparently is parallel to the corresponding boiling point line for the same liquid. Few data are, however, available, *v.* (157). The correction of Fl. P. to standard barometric pressure is therefore made in exactly the same way as the correction for boiling point, *q.v.*

Effects of Additions.—(*a*) Addition of lower boiling hydrocarbons lowers the Fl. P. (15, 179, 212, 214). (*b*) Addition of halogenated hydrocarbons usually raises but in some instances lowers the Fl. P. C_2Cl_6 and $C_2H_4Br_2$ are among the compounds producing the greatest increase in Fl. P. (16, 210). (*c*) Addition of water raises the Fl. P.; 6°C for 1% H_2O being given in one instance (146).

Relation between Fl. P. and Other Properties.—(*a*) Specific gravity: For gasolenes the relation Fl. P. (°C) = 800 × (sp. gr. − 0.729) ± *ca.* 2°, agrees with the data of (195). *See also* (156). Boiling point, *v.* (48, 49, 94).

Fire Point.—The literature cited above contains a few values for fire points.

Mixtures.—For method of calculating the Fl. P. of a mixture from the Fl. P. of its constituents, *v.* (83).

Pure Liquids.—*See* p. 161.

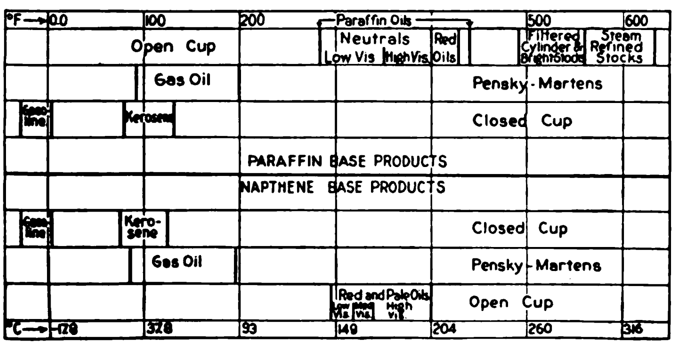

FIG. 6.—Average flash point range of petroleum oils.

IGNITION TEMPERATURES IN HIGH PRESSURE AND LOW PRESSURE OXYGEN

Material	Fl. P. °C	Ignition temperature, °C	
		1 atm.	33 atm.
Sperm oil	236	308	140
Lard oil	240	273	144
Castor oil	263	325	153
Glycerine		412	205
Kerosene	55	255	175
Spindle oil	194	248	178
Turbine oils			253–291
Compressor oil, A		309	188
Compressor oil, B	196	273	187
Compressor oil, C	216	286	157

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THERMAL CONDUCTIVITY AND DIFFUSIVITY

$$k = \mathrm{A} \times 10^{-6}\ \text{cal cm}^{-2}\ \text{sec}^{-1}\ (°\text{C, cm}^{-1})^{-1}$$
$$= 4.18\ \mathrm{A} \times 10^{-6}\ \text{joule cm}^{-2}\ \text{sec}^{-1}\ (°\text{C, cm}^{-1})^{-1}$$
$$= 0.806\ \mathrm{A} \times 10^{-6}\ \text{BTU}_{60}\ \text{ft.}^{-2}\ \text{sec}^{-1}\ (°\text{F, in.}^{-1})^{-1}$$

Designation of material (M. P. and sp. gr.)	t°C	A	Lit.
Paraffin	−198	828	(59)
Paraffin	− 78	887	(59)
Paraffin	0.0	688	(59)
Paraffin	20	285	(147)
Paraffin, 50.4°	0.29	372	(209)
	0.34	473	(209)
Paraffin, 66°, 0.92	23	640	(97)
Paraffin, 54°	0–14	571	(155)
Paraffin	0–31	558	(155)
Paraffin, 84°	0–13	608	(155)
Paraffin, 84°	0–26	584	(155)
Paraffin, 84°	0–33	564	(155)
Paraffin, 84°	22–48	489	(155)
Paraffin, 84°	21–57	470	(155)
"Paraffinöl," M. P. < −20°	0–29	331	(209)
	0–34	368	(209)
Cylinder oil	81	290	(58)
"Vaseline"		440	(110)
Kerosene	0–29	368	(209)
	0–34	403	(209)

Designation of material (M. P. and sp. gr.)	t°C	$\alpha = d_k/d_t$ per °C	Lit.
Paraffin		+0.0634 (?)	(207, 208)
Paraffin	10–45	−0.0076	(107)
Kerosene		+0.011	(75)

Diffusivity $= \dfrac{k}{c \times d} = 10^{-6}\mathrm{B}\ \text{cm}^2\ \text{sec}^{-1}$, where c = specific heat and d = density. For kerosene at 13°C, B = 890 (75).

SPECIFIC HEAT

A recent critical examination ((36) *q.v.* for bibliography) of all the available data for animal, vegetable and mineral oils together with many new determinations shows that the data for all types of oils are well represented by the following equation:

$$c_p = \frac{A}{\sqrt{d_4^{15}}} + \mathrm{B}(t - 15)\ \text{g cal/g},$$

where d_4^{15} is the density at 15°C and A and B are constants characteristic of the class to which the oil belongs, as shown by the following table and Fig. 7.

Oil	No. of samples	A	Av. dev. ±	Max. dev. ±	10^3B	Av. dev. ±	Max. dev. ±
Paraffin base	15	0.425	0.002	0.004	0.90		
Naphthene base	7	0.405	0.002	0.004	0.90		
Mixed base	8	0.415	0.002	0.004	0.90		
Fatty, non-drying	7	0.450	0.001	0.002	0.70		
Fatty, semi-drying	1	0.445			0.70		
Fatty, drying	1	0.440			0.70		
Castor		0.500			0.70		
Petroleum oils	30	0.415	0.007	0.013	0.90	0.03	0.06
Fatty oils (except castor)	9	0.450	0.003	0.010	0.70	0.03	0.05

Latent Heat of Fusion

Paraffin, 35–39 g cal/g (72).

Latent Heat of Vaporization

Recorded data mostly fragmentary. In the following summary, the values given are calories per gram: 1 cal g⁻¹ = 1.800 BTU$_{60}$ lb.$^{-1}$; 10 gasolenes, 71–81; 2 kerosenes, 60; 1 light crude, 75.6; 1 heavy crude, 86; 1 gas oil, 69; 1 light "vaseline," 63; 1 heavy "vaseline," 54; 1 "cleaning oil," 66.5 (73, 152, 170).

One investigation of a series of 12 petroleum fractions with boiling points (t_B°C) ranging from 67° to 300°, gives the following: $l = (93.4 - 0.187t_B)$ cal g^{-1} at t_B (114) *cf.* (152).

Investigation (81) of a series of fractions of Baku petroleum gave:

Sp. gr.	0.640	0.698	0.743	0.762	0.797	0.813
t_B°C.	40	72.8	92.2	100.7	155.7	175.5
l, cal/g.	80.6	75.0	68.3	66.6	53.6	51.6

CALORIFIC VALUES

The heats of combustion, H, (at constant volume, to produce liquid water and gaseous CO_2) of petroleum products can be very satisfactorily represented as a linear function of their specific volumes, the parameters of the equation varying slightly according to the type of product. The equation may be conveniently written in the form

$$H = A + B\left(\frac{1}{d} - 1\right),$$

where H is the heat of combustion per gram, d is the density in g cm^{-3}, and A and B are constants. From the data reported in the literature the constants A and B have been evaluated and the results are set forth below.

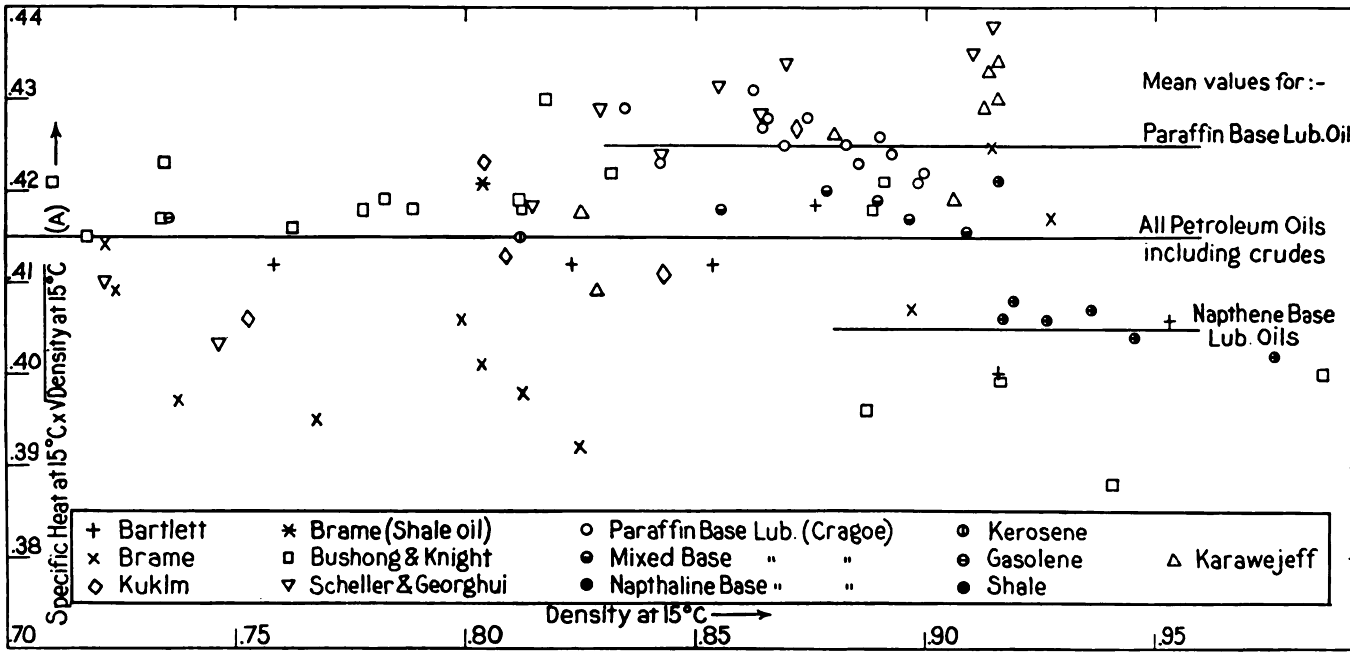

Fig. 7.—Specific heat of petroleum products.

1 kg-cal$_{15}$ g^{-1} = 1800 BTU$_{60}$ lb.$^{-1}$ = 4.185 kj g^{-1}

Type	No. of samples	$H = A + 4(1/d - 1)$ kg-cal per g A	Dev. $H_{obs.} - H_{calc.}$ Average Plus	Average Minus	Maximum Plus	Maximum Minus
Crudes (6, 7, 31, 39, 74, 104, 154, 183, 185, 189, 198, 223)	164	10.14	0.08	0.11	0.77	0.19
Distillates						
d from 0.67 to 0.75	44	9.69	.17	.25	.77	.67
d from 0.75 to 0.85	41	10.03	.16	.21	.95	.83
d from 0.85 to 0.90	83	10.20	.07	.10	.21	.70
d from 0.90 to 0.97 (5, 22, 28, 31, 34, 39, 96, 118, 151, 154, 164, 167, 170, 177, 189, 196, 223).	38	10.30	.12	.08	.45	.25
"Lubricating oil" (190)	3	10.27	.02	.01	.02	.03
Coal tar oils (32)	8	9.69	.15	.09	.24	.18
Coal tar oils (223)	3	10.02	.03	.06	.06	.06

For the following products density data were not available and the values given are H in kg-cal g^{-1}.

Paraffin	11.09 and 11.17 (194).
Ozokerite	10.65 and 10.95 (141, 183).
Coal tar oil	9.94 and 10.22 (96, 154).

REFRACTIVE INDEX

The function $\frac{n_D - 1}{d}$, where n_D is the refractive index for the D line (approximately daylight) and d is the density, both at the same temperature, is approximately a constant for all types of petroleum products, varying between the extreme limits of 0.53 and 0.61. For a set of distillates from a given crude the value of this function for the crude and for all of its distillation fractions is apparently constant within 1 to 3%. In the table below are shown for various types of products (1) the number of samples included in the average; (2) the average and extreme values of $\frac{n_D - 1}{d}$ at room temperatures, or similar values of n_D for samples for which d values were not available.

Designation of product	No. of samples	$\frac{n_D - 1}{d}$ Low	Av.	High	Lit.
Crudes	17	0.530	0.554	0.567	(54, 62, 112)
Ligroin	1		0.552		(199, 203)
Benzine	13	0.531	0.557	0.567	(62, 199, 203)
"Turpentine substitute"	3	0.54	0.558	0.57	(199, 203)
Naphtha	4	0.558	0.560	0.563	(62, 203)
Gasolene	23	0.557	0.566	0.577	(62, 112, 203)
Kerosene	11	0.553	0.556	0.563	(62, 112, 199, 207)
"Gas oil"	4	0.554	0.556	0.558	(62)
Pressure distillate	2	0.563		0.564	(62)
Mineral oils	4	0.562	0.563	0.564	(178)
Liquid paraffin (Ph. G.)	5	0.542	0.543	0.543	(203, 68)
Wax distillate	3	0.560	0.565	0.608	(62)
Distillation fractions for various intervals of each of the total ranges given.					
140°–310°C	20	0.543	0.556	0.572	(50)
40°–300°C	50	0.556	0.559	0.578	(111)
195°–282°C	10	0.555	0.557	0.557	(26)
50°– 60°C	1		0.562		(159)
340°–350°C	1		0.581		(159)
		Values of n_D			
Petroleum ether	1		1.375		(203)
Mineral oil	2	1.478		1.498	(91)
Spindle oil	2	1.477		1.489	(168, 203)
Lubricating oil		1.478		1.517	(94)
Machine oil	1		1.498		(203)
Petroleum jellies—"vaseline," at 15°C	7	1.471	1.474	1.498	(203)

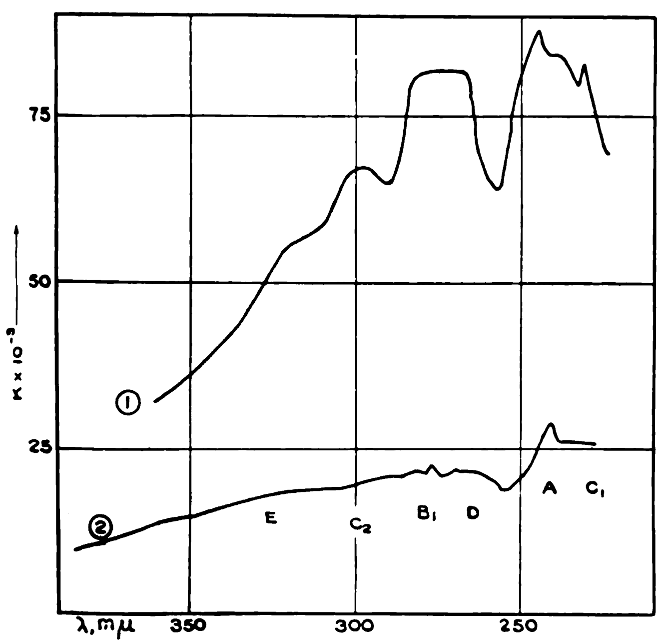

Fig. 8.

Paraffins and Mineral Waxes.—Recorded data on n_D at various temperatures between 15° and 100° for 35 samples with melting points from 36° to 61°C, range from 1.415 to 1.446, density data on the samples unfortunately not being given (29, 65, 68, 168, 203). For 3 ozokerite samples, 40°–90°, n_D = 1.42 to 1.53 (68). For 16 ceresin samples, M. P. 57°–73°, t = 15° to 100°C, n_D 1.426 to 1.454 (29, 68, 168, 203). $\frac{dn_D}{dt} = -0.00039$ to -0.00043 per °C for paraffin; -0.00047 per °C for ceresin (68, 221).

Effect of Acid Washing.—For effect of washing and filtering on n_D of petroleum distillates *v.* (62, 132).

OPTICAL ACTIVITY

Most petroleum products contain optically active constituents. The reported values of the specific rotatory power $[\alpha]_D$ (*v.* vol. I, p. 41) range from $-1°$ to $+9°$ of arc per decimeter per (g per cm³), the lower value being reported for a 134–142°C boiling point (11.5 mm Hg) fraction from a Roengkoet crude (53.1) and the higher value for a 216°C B. P. fraction from an Argentine (Mendoza) crude (57). For detailed data *v.* (52, 53, 53.1, 56, 57, 164, 192, 224).

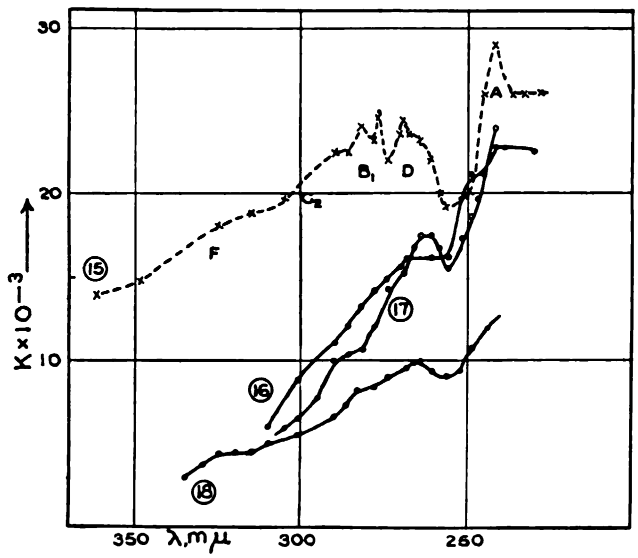

Fig. 9.

COEFFICIENT OF LIGHT ABSORPTION (204)

In Figs. 8, 9, 10, 11, the coefficient of light absorption, K, of various petroleum products in solution in chloroform is graphed against the wave lengths in millimicrons.

$$K = \frac{\log \frac{J_0}{J}}{Cl}$$

where J_0 (resp. J) = intensity of initial (resp. emergent) radiation, C = concentration of the oil in $CHCl_3$ in g/cm³, and l = absorption thickness. In the various experiments the quantity $1/Cl$ was varied between 50 and 4×10^4.

Designation of Oils

Number	Oil	Number	Oil
1	Tar	10	Crude kerosene
2	Dry crude petroleum oil	11	Cleaning oil
3*	Crude petroleum oil	12	Rectified kerosene
4	Crude gasolene	13	Refined kerosene
5	White spirit (gasolene)	14	White spirit
6	Heavy gasolene	15	Dry crude petroleum oil
7	Light rectified gasolene	16	Crude machine oil
8	Light refined gasolene	17	Refined machine oil
9*	Crude petroleum oil	18	Crude paraffin

* For these curves, multiply the ordinates by 330.

IODINE AND BROMINE NUMBERS

("Olefins," "unsaturation")

Values reported range over wide limits and "type characteristic" values apparently do not exist. Time, temperature, concentrations of reagents, and other test conditions influence the results obtained. The original literature must be consulted. In the following summary I = iodine No., Br = bromine No.

Crudes.—Br, 0.6 to 17 (53.1); I, 0.0 to 15 (53.1, 98, 185, 104).

Distillates.—Br, 0.5 to 95 (4, 53.1, 98, 144, 202); I, 0.0 to 100 (53.1, 61, 69, 71, 94, 98, 163, 177).

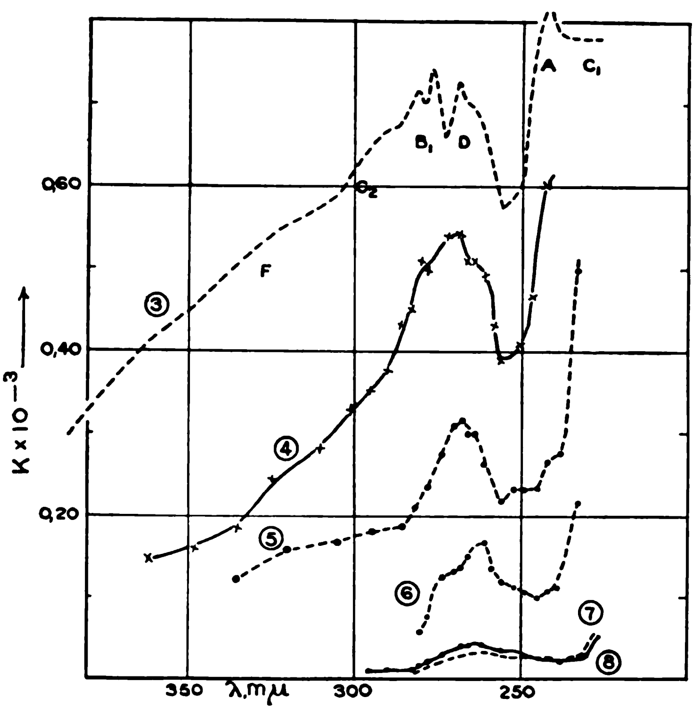

Fig. 10.

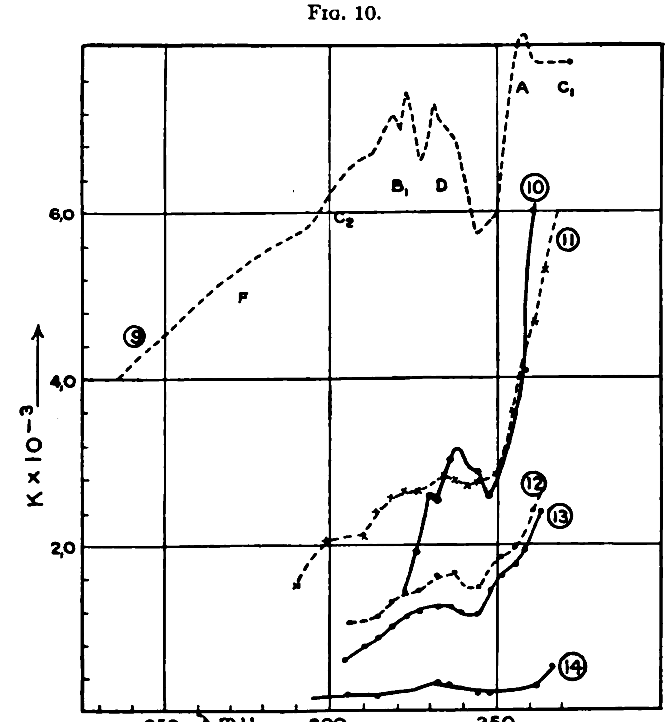

Fig. 11.

Lubricating Oils.—Br, 0.0 to 56 (4, 144); I, 0.4 to 57 (15, 53.1, 163, 185).

Waxes and Jellies.—Br, 0.5 to 20 (4, 144); I, 0.4 to 21 (3, 15, 46, 60, 71, 86, 98, 100, 101, 116, 163, 180, 191).

Transformer Oils.—(163).

Bibliography.—(98).

Some Sample Values.—The following values are by one observer, using the Hanus method, but with CCl_4 as the solvent for the halogen. A = "addition value," S = "substitution value" (98).

IODINE AND BROMINE VALUES OF TYPICAL PETROLEUM PRODUCTS

	Grams used	Iodine value			Bromine value		
		A	S	A+2S	A	S	A+2S
Pentane	1	0.37		0.37	0.39	0.06	0.51
Straight run naphtha	1	0.53	1.58	3.69	0.65	1.55	3.75
Straight run naphtha (treated)	1	0.47	1.14	3.29	0.64	1.44	3.52
Cracked naphtha	1	14.70	8.16	31.02	9.39	4.62	18.63
Cracked naphtha (treated)	1	10.72	8.48	27.68	6.80	5.65	18.10
Straight run lamp oil distillate	1	1.32	5.04	11.40	0.69	3.13	6.95
Straight run lamp oil distillate (treated)	1	0.74	5.06	10.86	0.48	3.00	6.48
Cracked lamp oil distillate	0.5	23.23	9.52	42.27	21.81	7.57	36.95
Cracked lamp oil distillate (treated)	0.5	17.59	10.63	38.85	16.42	8.57	33.56
Straight run gas oil	1	2.56	9.62	21.80	2.44	3.93	10.30
Cracked gas oil	1	4.59	14.26	33.11	4.45	7.22	18.89
Lubg. stock (uncracked)	1	0.83	12.06	24.95	2.09	5.83	13.75
Lubg. stock (uncracked, filtered)	1	0.32	11.48	23.28	1.55	5.78	13.11
Lubg. stock (from run to coke)	1	0.85	14.43	29.71	3.55	9.48	22.51
Lubg. stock (from run to coke, treated)	1	0.42	13.32	27.06	1.39	7.17	15.73
26½ cylinder stock (Pa.)	1	2.29	10.99	24.27	1.76	6.43	14.62
26½ cylinder stock (filtered)	1	0.21	11.67	23.55	0.64	6.56	13.76
Petrolatum stock	1	11.31	7.26	25.83	6.93	3.10	13.13
Petrolatum stock (filtered, U. S. P.)	1	1.76	11.31	24.38	2.43	4.40	11.23
Refined paraffin wax (132° M. P.)	1	1.10		1.10	1.16	2.25	5.66
Amorphous wax from petrolatum (165° M. P.)	1	1.32	2.90	7.12	1.38	1.50	4.38
White medicinal oil	1	0.05		0.05	0.40	1.90	4.20
86–88 gasolene	1	1.74	0	1.74	0.58	0.34	1.26
70 gasolene	1	1.20	0	1.20	0.83	0.05	0.93
Motor gasolene	1	5.91	2.73	11.37	3.71	1.15	6.01
V. M. & P. naphtha (55°Bé)	1	2.00	2.51	7.02	1.47	1.10	3.67
Varnoline (51°Bé)	1	2.63	3.36	9.3	1.49	0.85	3.19

SULFURIC ACID ABSORPTION FOR GASOLENE

("Unsaturation," "olefins")

The reported data are mostly not systematically obtained and methods are ill-defined. In one investigation (40), however, 43 samples of gasolene were investigated both as to iodine No. (Hanus) and % absorption by 1.84 sp. gr. H_2SO_4. The I numbers ranged from 47 to 293 and the acid absorption from 8 to 46, the ratio showing an average value of 6.5 with 7.5 as maximum and 5.3 as minimum. For discussion of reaction between olefins and H_2SO_4 *see* (24).

GUM TEST

(37, 92, 93, 106, 187) and also (67), which contains a bibliography.

COMBINED PROPERTY TABLES

In this section are given, for comparison purposes, tables displaying values of several properties determined on the same sample of oil. In most instances these are expressed in the units given by the investigator.

Crude Petroleums

California Petroleums, Average Values

For values of *all* the samples examined, *v.* (6).

District	d_{15}^{15}	Open cup: Flash point °C	Open cup: Burning point °C	Viscosity at 20°C Engler	H_2O %	S %	Volume per cent: Naphtha unrefined	Fuel oil	Gasolene refined	Lamp oil refined	Lubricants refined	Refining losses	Distilling losses	Asphaltum (commercial)
Los Angeles City	0.963	107	145	272.5	1.7	0.6	0.0	98.3	0.0	4.5	32.1	12.5	0.6	48.6
La Brea, Salt Lake or Santa Fe	0.960	46	89	574.3	0.9	2.3	0.0	99.1	0.0	13.0	22.3	9.6	0.9	53.3
Fullerton	0.921	18	52	110.5	0.2	0.9	0.3	99.5	0.3	21.7	24.1	10.3	1.3	42.1
Brea Canyon	0.923	11	40	16.0	Tr.	0.9	0.1	99.9	0.1	23.1	24.5	10.9	1.2	40.2
Puente Hills	0.891	−2	18	3.1	Tr.	0.4	0.8	99.2	0.8	32.3	23.1	10.3	1.2	32.3
Whittier	0.939	46	84	34.6	0.0	0.6	0.0	100.0	0.0	17.1	30.1	12.6	0.6	39.6
Coyote Hills	0.905	27	50	10.5	Tr.	1.1	0.0	100.0	0.0	18.2	26.4	10.4	1.0	44.0
Newhall	0.925	60	83	118.2	0.2	0.4	0.1	99.7	0.1	23.0	27.7	10.8	0.8	37.3
Piru	0.914	23	47	47.0	0.2	0.7	0.4	99.4	0.4	21.7	28.1	11.1	0.6	37.9
Bardsdale	0.918	−1	30	22.5	4.2	1.9	1.8	94.0	1.8	16.7	25.7	9.8	0.7	41.1
Sespe	0.895	18	40	10.8	0.4	0.3	1.1	98.5	1.1	22.0	27.5	10.8	1.2	37.0
Santa Paula	0.902	6	18	5.8	0.5	0.5	1.2	98.3	1.2	25.4	27.2	10.9	0.7	34.1
Adams Canyon	0.920	38	55	11.3	Tr.	0.6	0.0	100.0	0.0	17.7	30.6	11.8	0.7	39.3
Wheeler Canyon	0.888	−12	2	2.3	0	0.5	1.3	98.7	1.3	28.6	25.4	9.9	1.0	33.8
Summerland	0.965	100	130	222.1	1.2	0.4	0.0	98.8	0.0	1.2	39.8	14.7	0.5	42.6
Santa Maria	0.905	−2	20	19.0	0.1	1.9	2.0	97.9	2.0	26.1	22.5	9.2	1.5	38.6
Lompoc	0.934	−1	21	62.5	0.7	3.6	0.0	99.3	0.0	17.0	18.4	7.5	1.1	55.3
Arroyo Grande	0.975	109	154	1322.2	0.2	1.1	0.0	99.8	0.0	0.0	29.1	11.2	0.4	59.1
Coalinga	0.939	70	93	80.7	0.4	0.5	0.0	99.6	0.0	7.6	37.2	14.2	0.5	40.1
Midway	0.932	54	83	91.7	0.6	0.7	0.0	99.4	0.0	15.9	33.5	13.2	0.7	36.1
Sunset	0.942	47	79	120.5	0.5	0.8	0.3	99.2	0.3	14.6	30.3	11.8	0.9	41.6

Rumanian Petroleums

Source	Sp. gr. 15/15 °C	Boiling point limits °C	Wt. % dist.	Sp. gr.	% paraffin: Dist.	% paraffin: Crude	Elementary analysis wt. %: C	H	O	N	S	Specific heat cal g^{-1}	Viscosity centipoises	Hübl-Waller iodine No.	Acidity as SO_3	Treating loss*
Moinesti	0.869	80–150	8.9	0.730												
		150–300	33.8	0.814	10.64	5.04	85.8	13.1	0.35	0.28	0.44		13	7.7	0.04	48.0
		>300	57.3													
Bustinari	0.842	75–150	26.6	0.737												
		150–300	32.7	0.821	0.77	0.25	86.0	13.3	0.29	0.31	0.15	0.463	5.8	3.7	0.17	30.0
		>300	40.7													
Campina, rich in paraffin	0.855	85–150	12.6	0.738												
		150–300	36.7	0.815	7.30	3.18	85.1	13.7	0.81	0.24	0.15	0.468	8.4	5.3	0.07	34.0
		>300	50.7													
Campina, poor in paraffin	0.869	87–150	12.7	0.739												
		150–300	34.7	0.825	1.71	0.76	86.3	12.5	0.77	0.27	0.2	0.467	13.1	6.5	0.18	48.0
		>300	52.6													
Filipesti	0.853	91–150	17.2	0.725												
		150–300	33.1	0.809	11.60	4.97	86.6	13.0		0.29	0.17		5.6	27	0.007	29.0
		>300	49.7													
Policiori	0.829	94–150	9.9	0.750												
		150–300	53.6	0.813	13.92	4.6	85.8	12.2	1.55	0.27	0.15	0.472	4.4	1.7	0.007	18.5
		>300	36.5													
Moreni	0.888	73–150	14.8	0.746												
		150–300	29.6	0.844	0.67	0.29	86.4	10.2	2.79	0.30	0.24		22	5.9	0.34	47.5
		>300	55.6													
Baicoi	0.881	56–150	23.8	0.743												
		150–300	25.0	0.841	0.41	0.16	85.7	12.9	0.85	0.30	0.2		11	8.8	0.25	72.0
		>300	51.2													

* Loss on shaking 4 parts 66° H_2SO_4 and 1 part oil for 15 minutes at 25°C (183).

Various Crude Petroleums

Source	d_{15}^{15}	Flash point °C	Viscosity: Engler°	Viscosity: t°C	Amount of distillate, vol. %: to 130°C	130–270°C	270–300°C	Residue vol. %
California	0.962	82	4.3	80			32	68
Coalinga	0.958	111	3.1	80			31	69
Argentina	0.940	124	13.6	80			24	76
Peru	0.865	<15			21	29	9	41
Pennsylvania	0.805	<15			12	50	13	25
Mexico	0.934	24	11	15	7	38	31	24
Texas	0.944	120	34	20		16.8	12.2	71
Sumatra	0.792	<0				50.5	4	11.5
Rumania	0.854	<15			20	35	7	38
Wietze	0.942	105	15	50		11.9	8.8	79.3
			4.7	80				
Alsace (upper layer)	0.880	<15			5	22	7	66
Russia	0.873	38				40	13	47
Galicia	0.862	<15			20	45	11	24
			Sec		to 175°	175–300°	300–360°	
Argentina (119)	0.96	41	350.6	50	3.4	12	17	62.7

Hydrocarbon Oils (154)

Designation	d_{15}^{15} (* = d_{15}^{18})	% composition: C	H	S	O and N	Open cup: Flash °C	Fire °C
Fuel oil	0.921	85.3	11.9	0.6	2.2	133	164
Crude	.923			0.5		125	155
Light fuel	.900*	88.6	10.8	0.4	0.2	187	220
Admiralty fuel	.928	86.4	11.6	0.3	1.7	138	163
Residuum	.943*	86.4	11.2	0.3	2.0	166	197
Black oil	.928	86.4	11.8	0.5	1.2	144	172
Refined oil	.904*	85.1	12.2	0.4	2.4	122	135
Rumanian crude	.825			0.2		Room	
Rumanian crude	.830	83.8	13.0	0.3	3.0	Room	
Texas solar	.862*	85.4	12.9	0.2	1.6	92	97
Scottish shale oil	.855*	86.2	12.4	0.3	1.2	129	158
Scottish shale oil	.862	85.4	12.4	0.3	1.7	130	150
Scottish shale oil	.867			0.3		130	148
Gas oil	1.067	87.6	6.0	0.7	5.7	90	109
Gas oil	1.004	83.7	7.3	0.8	8.2	77	86

Hydrocarbon Oils (29)

Source	d_{15}^{15}	B. P. Range °C	Index of ref. n_D^{15}	Rieke and Halphen sol. index	Crit. diss. temp. in alc., °C	Turbidity temp. in acetic anhydride, °C
Naphtha fractions						
American	0.780	— to 191	1.4345	93	50	78.5
American	0.800	191 –227	1.4453	117	68.5	91
American	0.820	227 –266	1.4563	154	87	104.5
Russian	0.780	— to 158.5	1.4309	75	36	66
Russian	0.800	158.5–182	1.4419	85	47.5	72
Russian	0.820	182 –219.5	1.4533	92	60	79.5
Rumanian	0.780	— to 153	1.4334	73	Clear	53
Rumanian	0.800	153 –179	1.4458	79.5	30	57
Rumanian	0.820	179 –207.5	1.4572	90.5	42	63.5
Galician	0.780	— to 166	1.4356	74	31	60
Galician	0.800	166 –202	1.4466	94	53	75.5
Galician	0.820	202 –242	1.4586	125.5	72.5	89.5
Shale	0.780	— to 167.5	1.4373	74	31	54.5
Shale	0.800	167.5–198	1.4469	92.5	42.5	63
Shale	0.820	198 –227.5	1.4568	109	54	71
		Luchaire flash				Solidification
Russian spindle	0.894	198	1.4888		150	<−15
American cylinder	0.891	255	1.4950		194	0

Typical Lubricating Oils

Average values representative of one large manufacturer. Other companies may produce products whose tests vary widely from those listed below

Specific gravity 60/60°F	Cleveland O. C.: Flash °F	Fire °F	Saybolt viscosity: 70°F	100°F	Pour point °F	N. P. A. color
Neutral Oils						
0.843	275	325	45		25	1
0.849	285	330	50		25	1
0.854	325	375	70		25	1
0.859	330	385	65	70	25	1½
0.862	350	405	87	85	25	1½
0.864	375	425	105	100	25	2
0.867	380	435	120	110	25	3
0.870	395	450	130	120	25	3
0.872	400	455	150	140	25	4–5
0.875	410	475	185	165	25	5
0.878	420	485	200	180	25	6
Western "Neutrals"						
0.883	370	430		140	30	3
0.889	375	435.		170	25	3
0.892	385	440		200	25	3
0.895	390	450		230	25	4
0.897	395	455		250	25	4
0.900	400	460		280	25	5
Paraffin Oils						
0.870	325	380	70	65	30	2½
0.875	330	385	80	70	30	2½
0.878	345	400	85	80	30	2½
0.881	350	405	90	85	30	2½+
0.886	355	410	105	100	35	2½+
0.892	375	430	180	155	35	3
0.897	395	450	205	180	35	3
0.900	400	460	250	210	40	4
0.903	410	480	310	250	40	5
0.909	415	485	350	280	40	6
0.912	420	490	370	290	40	6+
Naphthene Base. Gulf Coast*						
0.924	295	335	100		0	2½
0.927	320	365	200		0	3+
0.930	340	400	300		0	3+
0.933	350	410	360		0	3+
0.933	360	415	500		0	3½+
0.937	385	440	750	60	0	3½+
California*						
0.921	295	345	100 .		0	3
0.927	310	350	150		0	3
0.933	330	365	205		0	3½
0.940	350	390	400		0	4
0.943	365	415	450		0	4½
0.946	380	430	850		0	6
Cylinder Stock Pennsylvania, Bright, Cold-Settled*						
0.892	535	600		140	45	FF
0.897	540	605		152	40	FFF
0.900	545	610		168	40	FFF

* Viscosities at 100° and 210°F.

Gas Oils and Derived Tars and Their Distillates (175)

All data for 20°C unless indicated otherwise. Charge for distillations 400 cc

	Gas oil No. 1				Gas oil No. 2				Gas oil No. 3				Gas oil No. 4			
$d^{15.5}_{15.5}$	0.872				0.858				0.872				0.890			
Surface tension γ (dyne per cm)	28.60				28.40				28.54				28.91			
Viscosity (specific)	2.3								2.1				6.8			
Temperature, °C	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}
150	0.9	0.790	22.40	1.416	1.3	0.788	22.22	1.419	1.1	0.759	21.59	1.412	0.8	0.775	23.38	1.426
200	1.5	0.800	24.30	1.434	1.1	0.798	24.29	1.442	2.2	0.778	23.79	1.434	3.1	0.794	24.32	1.437
225	1.1	0.809	25.57	1.441	2.0	0.814	25.97	1.448	2.3	0.799	25.22	1.448	4.8	0.815	25.36	1.446
250	4.2	0.818	26.28	1.454	5.6	0.824	26.87	1.453	3.0	0.817	26.23	1.455	6.4	0.832	26.43	1.454
275	5.4	0.836	27.60	1.464	6.2	0.832	27.41	1.458	6.1	0.837	27.18	1.464	6.8	0.845	27.07	1.462
300	12.2	0.849	28.12	1.472	8.0	0.842	27.86	1.464	9.9	0.851	28.06	1.472	9.5	0.853	27.67	1.469
Mixed distillate	25.4	0.837	27.16	1.463	24.2	0.828	26.90	1.458	24.6	0.830	25.77	1.462	31.4	0.833	26.60	1.458

	Tar oil No. 1				Tar oil* No. 2				Tar oil* No. 3				Tar oil No. 4			
$d^{15.5}_{15.5}$	1.071				1.090				1.122				1.086			
Surface tension γ (dyne per cm)	33.83				34.83				36.55				37.6			
Viscosity (specific)	4.04				11.86				10.9				5.60			
Temperature, °C	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}	Vol. %	$d^{15.5}_{15.5}$	γ	n^{20}_{D}
150	1.9	0.870	27.49	1.491	0.8				1.2				3.1	0.874	27.44	1.499
200	4.4	0.903	29.44	1.520	0.9	0.940	30.26	1.531	1.6	0.942	30.28	1.532	7.0	0.916	29.13	1.529
225	6.5	0.940	30.95	1.541	1.1	0.956	32.44	1.562	3.1	0.977	33.66	1.557	6.9	0.956	30.69	1.553
250	11.2	0.975	32.39	1.569	4.2	0.984	33.31	1.576	6.5	1.012	35.21	1.572	11.4	0.986	32.16	1.576
275	8.2	0.983	32.61	1.572	12.3	0.993	33.51	1.582	10.8	1.027	35.69	1.585	10.5	0.998	32.84	1.587
300	7.2	0.995	32.95	1.579	6.0	1.010	33.79	1.589	6.3	1.047	36.08	1.594	5.8	1.018	33.25	1.597
Mixed distillate	39.4	0.970	31.95	1.562	25.3	0.983	32.20	1.578	29.5	0.968	34.10		44.7	0.968	31.66	1.566

* Much difficulty was experienced in distilling tar oils Nos. 2 and 3, owing to the presence of water.

Typical Lubricating Oils.—(*Continued*)

Specific gravity 60/60°F	Cleveland O. C. Flash °F	Cleveland O. C. Fire °F	Saybolt viscosity 100°F	Saybolt viscosity 210°F	Pour point °F	N. P. A. color
Mid-Continent, Bright, Cold-Settled						
0.961	510	570		145	45	Lt. D.
Texas, Bright (Naphthene Base)						
0.921	535	600		150	30	6
Filtered Cylinder Stock (Steam-Refined)						
0.881	450	525		90	75	
0.886	505	570		100	90	D
0.889	520	590		135	80	D
0.892	540	625		140	75	E
0.897	550	640		150	60	E
Unfiltered Cylinder Stock (Steam-Refined). * = Mid-Continent						
0.897	550	615		140	35	
0.900	555	620		150	35	
0.903	560	625		160	40	
0.906	575	645		185	40	
0.909	590	660		200	35	
0.912	600	690		240	40	
0.915	625	710		575	50	
0.921	645	730		290	50	
*0.915	510	570		140	50	
*0.915	535	600		175	50	
*0.927	525	605		180	40	

Continued on p. 158

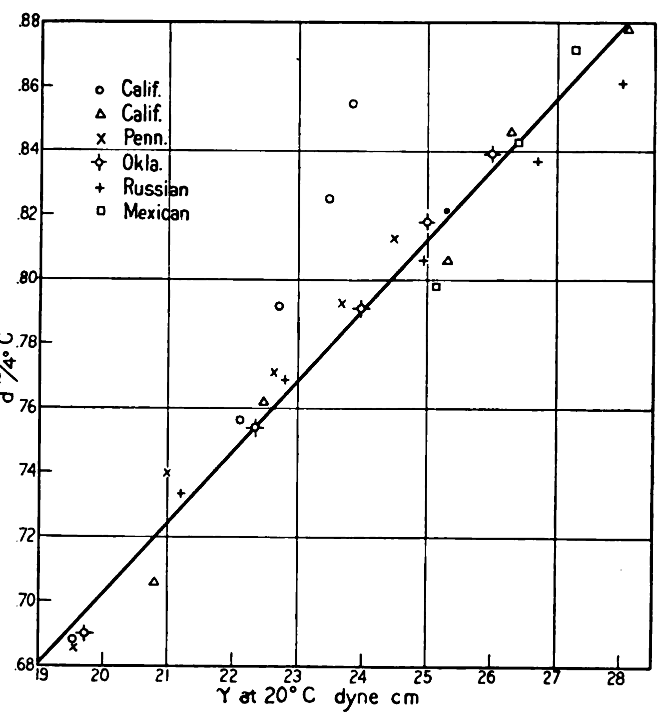

Fig. 12.—Variation of surface tension of petroleum distillates with density.

For comparison of the physical properties of petroleum distillates from different crudes *see* Fig. 3 (p. 149).

Typical Lubricating Oils.—(*Continued*)

Specific gravity 60/60°F	Cleveland O. C. Flash °F	Cleveland O. C. Fire °F	Saybolt viscosity 100°F	Saybolt viscosity 210°F	Pour point °F	N. P. A. color
			Black Oils			
0.881	320	370		35	20	
0.886	350	400		50	10	
0.895	375	425		60	15	
0.897	400	450		80	35	
0.915	420	470		100	30	

Various Lubricating Oils (105)

Bk = Black; Bl = Blue; Br = Brown; G = Green; O = Orange; R = Red; t = Translucent; W = White; Y = Yellow

Designation	Source	d_{15}^{15}	Solidification point °C	Flash point °C Pensky Martens closed cup	Viscosity Engler ° 25°C	Viscosity Engler ° 50°C	Color
Light Lubricating							
Vaseline oil......	Russia	0.870	< −30	150	4.5		W
Medium spindle..	Russia	0.890	< −30	155	5.3		Y
Heavy spindle....	Russia	0.900	< −20	180	9.0		Y
Thin spindle.....	Penn.	0.865	− 3	155	3.0		Y
Average spindle..	Penn.	0.875	− 1	185	5.0		Y
Medium Lubricating							
Machine.........	Penn.	0.890	0	195	8.0	3.2	R-Y
Machine.........	Penn.	0.917	3	205	16.0	4.6	G-R-t
Machine.........	Lima	0.921	− 2	205	16.5		G-R
Machine.........	Germany	0.920	5	170	17.0	4.9	G-R
Machine.........	Russia	0.909	< −15	195	14.0	4.2	O
Machine.........	Texas	0.932	< −15	175	14.5	4.4	G-R-t
Arctic...........	Penn.	0.878	2	200	7.6		G-R-t
Arctic...........	Lima	0.907	25	180	7.3		G-R-t
Turbine.........	Penn.	0.878	− 5	210	16.2		G-R-t
Heavy Lubricating							
Machine.........	Russia	0.910	< −15	195	27.0	6.3	O-R
Machine.........	Russia	0.913	< −15	200	36.0	8.0	Br-R
Machine.........	Germany	0.925	< −15	185	24.8		O
Machine.........	Germany	0.940	− 5	190	27.0	6.3	Bl-t
Machine.........	Texas	0.932	− 5	185	26.0	6.1	Br-R
Machine.........	Texas	0.936	−18	185		7.0	G-t
Machine.........	Texas	0.946	− 9	195		8.7	G-t
	Germany	0.932	− 8	180	35.4		G-t
	Texas	0.940	−20	180	26.5		G-t
	Texas	0.946	− 8	200		13.6	G-t
	Texas	0.950	− 7.5	205		14.3	G-t
Dark Lubricating			Pour point				
Winter..........	Russia	0.910	< −20	160	37.0	8.0	Bk-G
Summer.........	Russia	0.914	−12	155	50.9	11.0	Bk-G
Winter..........	Germany	0.927	< −20	155	16.5	5.0	Bk-Br
Summer	Germany	0.952	−10	185	440	9.6	
Bright Steam Cylinder					50°C	100°C	
Cylinder.........	Penn.	0.884	34	260	15.0	2.9	G-R
Cylinder.........	Penn.	0.886	30	275	23.0	3.5	G-R
Cylinder.........	Penn.	0.890	10	290	26.0	4.0	G-R
Cylinder.........	Russia	0.913	−15	220	12.0	2.3	Bl-R
Cylinder.........	Russia	0.915	− 5	235	15.0	2.9	Bl-R
Cylinder.........	Texas	0.955	− 5	215		2.7	G-R
Dark Steam Cylinder							
Cylinder.........	Penn.	0.895	5	280	29.0	4.0	G-Bk
Cylinder.........	Penn.	0.903	3	295	40.0	5.0	G-Bk
Superheated steam oil......	Penn.	0.905	0	325	60.0	7.0	G-Bk
Cylinder.........	Russia	0.928	0	280	30.0	4.1	G-Bk
Cylinder.........	Russia	0.928	0	255	50.0	6.0	G-Bk
Cylinder.........	Germany	0.950	7	270	27.0	3.8	G-Bk
Cylinder.........	Texas	0.954	−11	230		3.2	

Lubricating Oil from Blends of Stocks from Cushing and Bixby Crudes (62)

Sp. gr.	Cleveland open cup Flash °F	Cleveland open cup Fire °F	Viscosity 100°F seconds Saybolt universal	Cold test °F	Color N. P. A.	$\frac{n_D^{20}-1}{\text{Sp. gr.}}$
0.889	390	450	102	25	3	0.554
.889	395	440	100	23	3	.555
.887	350	405	95	24	2.5	.554
.896	400	430	184	26	3	.555
.895	405	445	172	26	4.5−	.555
.897	410	465	185	26	4	.556
.897	400	445	189	26	4.5+	.556
.897	395	445	180	24	4.5−	.556
.899	410	465	185	24	4.5−	.556
.899	400	445	198	26	5+	.557
.900	390	440	178	32	6−	.555
.900	400	460	196	25	6−	.555
.897	410	450	227	26	3−	.556
.902	405	465	246	28	4−	.555
.902			237	28	5+	.557
.903	415	470	227	28	6+	.557
.903	420	460	236	26	5+	.556
.901	410	460	226	28	Q	.557
.904	405	465	239	30	Q	.558
.904	410	460	250	34	6−	.558

Lubricating Oils for Internal Combustion Engines.—Oils designated by manufacturers' trade names. Sp. gr., flash and fire point, solidification temperature, viscosity at three temperatures, color. % distillation under 300°C, oxidation oven test (164.1).

Steam Turbine Oils (188)

Viscosity Engler° 20°C	Viscosity Engler° 50°C	d_4^{15}	Iodine No. Hübl-Waller	n_D^{20}	Resinification index 150°C Tar	Resinification index 150°C Coke	Resinification index 120°C Tar
			Oils of Good Quality				
8.80	2.60	0.875	14.2	1.4828	0.44	0.50	0.13
9.08	2.66	.876	12.8	1.4826	.37	.17	.12
9.1	2.61	.876	11.7	1.4814			.11
9.78	2.66	.904	5.8	1.5020	.68	.63	.24
10.8	2.81	.883	0.4	1.4795	2.10	0	1.05
13.8	3.32	.900	7.1	1.4965	.74	.82	0.37
19.3	4.08	.908	8.5	1.5034	.84	1.02	.39
22.5	4.32	.904	4.3	1.4940	.64	0.92	.39
31.7	6.4	.874	10.4	1.4826	.46	.57	.29
			Oils of Poor Quality				
20.9	4.73	0.873	10.4	1.4822	0.65	0.92	0.23
25.4	4.57	.905	3.9	1.4965			
28.7	5.13	.907	4.6	1.4948	.63	.79	.38
30.0	5.28	.905	6.1	1.4949	.82	1.10	.62
13.1	3.20	.904					.30
			A "Good Oil"				
9–14		0.870–0.905					0.2

Petroleum Oils for Diesel Motors (31)

d_{15}^{15}	Galicia	Germany	Rumania	Russia	N. America	Mexico	So. America	India	Japan
	0.86–0.89	0.725–0.94	0.89–0.95	0.876–0.95	0.865–0.95	0.86–0.97	0.85–0.99	0.89–0.95	0.92–0.96
Flash °C (Pensky Martens)	53–155	< −15 to 175	87–162	53–138	82–166	32–132	−10 to 144	92–150	131–164
Fire °C	77–170	< −15 to 203	106–194	78–180	103–200	58–162	−6 to 199	120–174	176–211
Residue dist. above 400°C, vol. %	0.0–3.9	0.2–15.0	1.0–23.0	1.5–11.5	2.2–16.5	0.3–23.0	4.0–21.0	0.0–4.9	2.5–15.0
Water %	0.0–0.8	0.0–9.8	0.0–0.8	0.0–0.0	0.0–3.3	0.0–9.56	Tr.–8.94	0.0–0.12	0.0–0.15
Ash %	0.0–0.4	0.0–0.6	0.0–0.2	0.0–0.16	0.0–0.4	0.0–0.64	0.01–0.17	0.0–0.03	0.0–0.19
Combustible %	>98.8	>90	99	99.8	>96	>89.8	>90.9	99.8	99.8
C %	85.6–86.9	85.1–86.8	86.5–87.4	86.1–87.5	84.2–86.9	83.0–85.1	85.5–87.0	86.5–87.7	87.0–88.0
H %	12.0–13.1	11.6–11.4	11.3–12.1	11.3–12.9	11.3–13.1	12.8–13.0	10.8–12.8	11.1–12.5	11.0–11.7
(O + N) %	0.1–1.2	0.0–1.2	0.6–1.5	0.5–0.9	0.2–2.0	0.5–1.7	0.9–1.8	0.2–1.0	0.2–1.0
S %	0.1–0.8	0.1–1.2	0.2–0.6	0.2–0.4	0.1–2.5	1.6–4.3	0.2–1.3	0.2–1.2	0.2–1.0
H per 1000 C	137–151	113–169	127–140	128–150	129–151	130–150	123–148	125–143	124–134
Coke %	0.21–1.0	0.5–5.6	1.11–3.8	0.9–3	1.9–6.4	0.14–10.9	1.9 –6.7	0.0–4.7	0.8 –5.4
Asphalt %	0.0 –0.01	0.0–8.5	0.0 –1.9	0.0–0.8	0.0–8	0.0 –19.15	0.17–14.9	0.38–7.90	0.09–1.46
Heat of combustion kg-cal/kg									
Net, Crude	9.95–10.9	8.93–10.4	9.78–9.99	9.80–10.2	9.29–10.1	8.49–10.1	9.0 –10.1	9.81–10.0	9.74–9.97
Net, Water-free oil	10.0 –10.2	9.87–10.4	9.78–9.99	9.81–10.2	9.6 –10.1	9.37–10.1	9.72–10.1	9.81–10.0	9.74–9.97
Gross	10.7 –10.9	10.5 –11.1	10.4 –10.6	10.4 –10.86	10.3 –10.8	10.1 –10.8	10.3 –10.8	10.4 –10.7	10.3 –10.6
Engler viscosity									
20°C	1.65– 2.96	5.24–136	18.1 –114	3–149	5.3– 11	1.62–317		10.4–14.8	12–302
35°C								4.1– 5.5	5.0–64
50°C	1.23– 1.56	2.04–17.7	3.56–13	1.6 –15	2.06– 2.58		43–205	3.0– 2.45	2.7–27
75°C							20–42		
100°C	1.02– 1.13	1.26– 2.43		1.14– 2.40	1.23–1.38	1.03– 4.47	6.3 –13	1.22–1.37	1.3–2.5

Tar Oils for Diesel Motors (32)

Source of tar	Coke oven	Water gas	Oil gas	Coal tar oil	Oven retorts		Vertical oven retort		Chamber oven
					Horizontal	Inclined	Dessau	Woodall-Duckham	
d_{15}^{15}	1.14–1.18	0.97–1.13	1.05–1.07	1.0–1.11	1.15–1.23	1.12–1.16	1.06–1.12	1.08–1.10	1.06–1.09
Flash point °C (Pensky Martens)	90–135	34–91	18–69	66–121	67–92	52–78	49–75	41–52	35–71
Fire point °C	108–166	50–*ca.* 155	20–89	84–160	93–129	79–107	70–102	71–90	70–93
Explosion °C	*ca.* 600		*ca.* 560	*ca.* 550	520–630	490–520	510–530	500–510	480–510
Distillate (ash H_2O free) vol. %: Light oil, 0–170°	0.0	1–12	2.5–23	0–12	1.0–6.6	1.5–6.7	1–9	3–8	2.5–10
Medium oil, 170–230°	1–17	6–23	11–16	0–59	10–14	14.7–18	16–24	13–17	21–24
Heavy oil, 230–270°	6–14	11–24	11–19	1–36	8.5–13	4.9–14	8.8–18	11–13	9–12
Anthracene oil, 270–350°	19–27	19–51	18–31	9–66	9.9–22	12.9–21	19–24.5	19–21	17–24
Pitch (residue) %	50–65	18–51	31–37	1–34	52–66	47.6–55	31–47	44–51	39–41
Coke in pitch %	16–34	25–39	33		32–47	32–40	16–27	20–25	21–22
C %	89.6–92.2	89.3–93.0	91.4–92.2	87.4–91.4	90.4–93	89.3–90.4	87.6–89.9	87.9–88.8	87.1–89.3
H %	5.1 –5.7	5.5–9.2	6.3–7.2	6.0–7.8	4.7–5.5	5.9–6.4	6.0–7.3	6.6–7.2	6.7–7.1
O + N %	2.2–4.0	0.4–1.7	0.5–1.1	1.4–4.9	1.7–3.2	3.2–3.9	2.6–4.9	4.1–4.7	3.6–5.2
S %	0.4–1.2	0.6–1.0	0.4–0.9	0.4–0.9	0.5–1.0	0.4–0.7	0.4–0.6	0.5–0.9	0.3–0.6
H per 1000 C	52–59	58–101	66–77	62–83	1.8–57	60–66	61–77	68–75	69–74
Comp. of Tar: Water %	0.6 –6.7	0.0–36	0.3–10	0.0–1.8	0.0–8.7	1–7.3	0.8–3.6	1.1–2.8	1.3–5.8
Ash %	0.04–0.36	0.0–0.67	0.0–0.2	0.0–0.04	0.0–0.06	0.01–0.07	0.00–0.09	0.00–0.03	0.0
Combustible %	93–99	63.1–100	89–99	98–100	91–100	92–98	96–99	97–99	94–98
Heat of Combustion kg-cal/kg									
Net: Experimental	8.27–8.85	*ca.* 5.65–9.57	8.18–9.31	8.84–9.12	8.06–8.74	8.15–8.71	8.62–8.82	8.59–8.76	8.28–8.76
Net: Water-free oil (calc.)	8.77–8.92	8.99–9.59	9.09–9.34	8.86–9.14	8.75–8.83	8.77–8.86	8.83–9.08	8.84–8.90	8.79–8.90
Gross	9.09–9.22	9.39–10.1	9.53–9.73	9.25–9.51	9.01–9.16	9.10–9.21	9.17–9.48	9.22–9.30	9.20–9.27
Coke	7.6 –17	3.1 –11	7.5 –11	0.4 –3.6	15–33	15–22	4–11	7–10	7.1–7.3
Free Carbon	2.2 –10	0.0 –4	0.0 –4	0.0 –0.2	9–28	10–19	1–6	3–6	2.3 –3.0
Naphthalene	0.5 –10	0.3 –10	0.0 –3	0.8 –10.5	4–6	1–3	0.2 –2.5	0.1 –1.0	0.6 –2.1
Engler viscosity: 20°C		1.8 –4.4		1.4 –2	43–150	23–115	2.5 –52	32–40	8–13
35°C	15–103				9–91	7–35	4–12	7–10	3–5
50°C	4.9–38				4–25	3–8.6	1.5–4	2.7–3.4	2.0–2.5
75°C	2.5–4.8								
100°C	1.4–1.7	1–1.2		0.95–1.07	1.5–2.4	1.5–2.2	1.0–1.4	1.2–1.4	1.18–1.22

Diesel Motor Oils (223)

Type of oil	d_{15}^{15}	Engler η, 80°	Flash °C	Fire °C	%H	%C
Lignite: Crude lignite oil	0.9	1.02			12.4	85.6
Lignite: Paraffin oil	.916	1.09	98	112	11.5	85.9
Lignite: Soft paraffin	.894	1.01	123	142	11.8	85.7
Petroleum gas oil	.855	1.13	74	107	13.6	83.7
Rumanian crude oil	.858	1.12	10	10	12.3	83.1

Diesel Motor Oils (223).—(*Continued*)

Type of oil	d_{15}^{15}	Engler η, 80°	Flash °C	Fire °C	%H	%C
Rumanian gas oil	0.853	1.08	66	101	12.2	85.0
Solar oil	.849	1.03	81	106	13.3	85.7
Tegernsee crude	.868	1.01	56	81	11.1	86.9
Texas gas oil	.892	0.98	114	128	12.2	86.4
Refined petroleum	.879	1.03	57	72	14.2	85.1

Gasworks and Coke Oven Tar Distillates and "Diesel Engine Tar Oils" (150)

Property	Coal tar distillates			Petroleum oils		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Sp. gr.	1.02	1.09	0.95	0.91	0.96	0.86
Water %	1.1	12	0	0.91	9.5	0
Carbon %	89.2	90.0	87.1	85.4	88.3	83.4
Hydrogen %	7.3	8.0	6.5	11.5	12.5	10.9
O + N %	3.9	4.8	3.0	1.3	2.2	0.07
Sulphur %	0.64	1.0	0.3	1.3	2.8	0.04
Ash %	0.005	0.10	0	0.05	0.39	0
Closed flash point °F	164	208	97	187	280	<60
Viscosity Redwood 70°F	9	23	7	780	4800	9
Gross BTU $\times 10^{-3}$	17.4	17.9	16.4	19.0	19.7	17.6
Net BTU $\times 10^{-3}$	16.6	17.2	15.9	17.8	18.5	16.5
Engler distillation % at 250°C	58	76	28	5	13	1
Engler distillation % at 300°C	80	94	51	19	24	13
Retort test % at 350°C				28.5	30	14
Coke yield %	3	15	1	3	12	0.2
Free carbon %	0.26	5.2	0			
Tar acids %	9.5	30	Tr.			
Asphaltum %				12.0	37	1.5
Spontaneous ignition °C	480	520	415	264	264	254

TERMINOLOGY AND SPECIFICATIONS FOR PETROLEUM PRODUCTS OF COMMERCE

The characteristics that should be possessed by a "good" petroleum product for use under a given set of conditions may be inferred from the specifications established by law, custom, or fiat for such products. Specifications of this character for different countries can be found in the following publications:

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FLASH POINTS OF SATURATED VAPORS OF COMBUSTIBLE LIQUIDS

E. H. Leslie and J. C. Geniesse

1. Pure Substances.—The flash point of the vapor above a liquid is the temperature at which ignition will occur. The observed value is materially dependent upon the type of apparatus used (*v.* p. 150 for comparison of values with different types of apparatus). The lower limit of the flash point of a pure liquid is approximately the temperature at which its vapor pressure is equal to B/kN where B is the barometric pressure, N is the number of moles of O_2 required for complete combustion of one mole of the liquid, and k is a constant varying with the type of apparatus employed *cf.* ([4]). The flash point varies with the barometric pressure at the same rate as the boiling point.

In the accompanying table are shown for a number of liquids; (*a*) the value of N, (*b*) the observed flash point as recorded in the literature and (*c*) the flash point as calculated from the above relation, assuming $k = 8$. A better agreement between observed and calculated flash point might perhaps be obtained by using different values of k for different types of apparatus but the recorded flash points vary greatly and a careful and comprehensive investigation is needed.

Formula	Name	N	Flash point: Observed	Flash point: Calculated, min.	Lit.
CS_2	Carbon disulfide	3	−25.5 to −20	−27	(4)
	Hydrocarbons				
C_6H_6	Benzene	7.5	−12 to 10	−13	(4, 5)
C_6H_{12}	Cyclohexane	9	−17	−17	
C_6H_{14}	Hexane	9.5	−18	−26	(4)
C_7H_8	Toluene	9	6.5 to 30	6.5	(4, 5)
C_7H_{16}	Heptane	11	−1 to 17	− 5	(5)
C_8H_{10}	Ethylbenzene	10.5	15.5	23	(4)
C_8H_{10}	Xylene	10.5	29 to 50	25	(5)
C_8H_{18}	Octane	12.5	17	15	(4)
C_9H_{12}	*n*-Propylbenzene	12	30.5	40.5	(4)
$C_{10}H_8$	Naphthalene		86		(4, 5)
$C_{10}H_{12}$	Tetralin		78		(3)
$C_{10}H_{14}$	*sec.*-Butylbenzene		52		(4)
$C_{10}H_{18}$	Dekalin		58		(3)

Formula	Name	N	Flash point: Observed	Flash point: Calculated, min.	Lit.
	Halides				
$C_2H_4Cl_2$	Dichloroethylene		17		(8)
$C_6H_4Cl_2$	*o*-Dichlorobenzene		77		(8)
$C_6H_4Cl_2$	*p*-Dichlorobenzene	9.5	67 to 78	55	(5, 8)
C_6H_5Br	Bromobenzene	8.5	65	42	(8)
C_6H_5Cl	Chlorobenzene	8.5	27.5 to 39	23.5	(5, 8)
	Alcohols and Phenols				
CH_4O	Methyl alcohol	1.5	−1 to 32	13	(4, 5)
C_2H_6O	Ethyl alcohol	3	9.0 to 32.0	14	(4, 5)
C_3H_8O	*n*-Propyl alcohol	4.5	22.5 to 45.5	25	(4, 5)
C_3H_8O	Isopropyl alcohol		11.75 to 14.5		(4)
$C_4H_{10}O$	*n*-Butyl alcohol		35 to 35.5		(4)
$C_4H_{10}O$	Isobutyl alcohol	6	27.5	28	(4)
$C_5H_{12}O$	Isoamyl alcohol	7.5	40 to 42	44	(4)
C_6H_6O	Phenol		79		(4)
$C_6H_6O_2$	Catechol		127		(4)
$C_6H_6O_2$	Resorcinol	6.5	152	160	(4)
$C_6H_6O_2$	Hydroquinol	6.5	165	167.5	(4)
C_6H_7O	Cyclohexanol (hexalin)		68		(3)
C_7H_8O	*o*-Cresol	8.5	81 to 83	79	(4, 5)
C_7H_8O	*m*-Cresol	8.5	86	89.5	(4)
C_7H_8O	*p*-Cresol	8.5	86	90.5	(4)
$C_{10}H_8O$	*β*-Naphthol	11.5	161	139	(5)
	Aldehydes, Ketones and Ethers				
C_2H_6O	Methyl ether		−41		(5)
C_3H_6O	Acetone	4	−18 to 2	−19	(2, 5)
$C_4H_{10}O$	Ethyl ether	6	−41 to −20	−43	(5)
C_7H_6O	Benzaldehyde	8	62.5	63	(5)
	Acids				
$C_7H_6O_2$	Benzoic acid	7.5	121 to 131	136	(4, 5)
	Esters				
$C_3H_6O_2$	Ethyl formate	3.5	−19.5	−18	(4)
$C_3H_6O_2$	Methyl acetate	3.5	−15.5 to 4.6	−15	(4)
$C_4H_7ClO_2$	Chloroethyl acetate		67		(8)

ESTERS.—(*Continued*)

Formula	Name	N	Flash point Observed	Flash point Calculated, min.	Lit.
$C_4H_7ClO_2$	Ethyl chloroacetate...		54		(8)
$C_4H_8O_2$	Ethyl acetate........	5	−5.0 to 5	−5	(4)
$C_4H_8O_2$	Methyl propionate...	5	−2.0	−3	(4)
$C_4H_8O_2$	*n*-Propyl formate.....	5	−3.0	−2	(4)
$C_4H_8O_2$	Isopropyl formate....		−5.5		(4)
$C_5H_{10}O_2$	*n*-Butyl formate......		17.5		(4)
$C_5H_{10}O_2$	Ethyl propionate.....	6.5	12.5	9	(4)
$C_5H_{10}O_2$	Methyl *n*-butyrate...	6.5	14	11	(4)
$C_5H_{10}O_2$	*n*-Propyl acetate.....	6.5	14.5	10.5	(4)
$C_5H_{10}O_2$	Isopropyl acetate.....		4.5		(4)

NITROGEN COMPOUNDS

Formula	Name	N	Flash point Observed	Flash point Calculated, min.	Lit.
$C_6H_3ClN_2O_4$	Dinitrochlorobenzene.		187		(5)
$C_6H_4ClNO_2$	Nitrochlorobenzene...		127		(5)
$C_6H_4N_2O_4$	*m*-Dinitrobenzene....		150		(5)

NITROGEN COMPOUNDS.—(*Continued*)

Formula	Name	N	Flash point Observed	Flash point Calculated, min.	Lit.
$C_6H_5NO_2$	Nitrobenzene........	7.5	88 to 90	89.5	(4, 5)
C_6H_7N	Aniline..............	9	71	70	(5)
$C_8H_{11}N$	Dimethylaniline......	12	61 to 76	70	(5)
$C_{10}H_9N$	α-Naphthylamine....	13.5	157	144	(5)

2. Mixtures.—*See* p. 150.

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(For a key to the periodicals see end of volume)

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QUANTITATIVE EFFECTS OF SOME COMPOUNDS UPON DETONATION IN INTERNAL COMBUSTION ENGINES

T. A. BOYD

The detonation or "knock" that characterizes combustion in gasoline engines under certain conditions is influenced primarily by the chemical composition or structure of the fuel, and secondarily by the compression to which the combustion mixture is subjected, by its temperature, and by the point in the cycle at which ignition occurs, as well as by some more minor factors, such as the shape of the combustion chamber and the location of the spark plug (1, 8). The principal types of compounds that may be used as fuels in the gasoline engine arrange themselves in the order of decreasing tendency to knock as follows (2, 8): ethers, paraffins, olefins, naphthenes, aromatics, alcohols. The tendency of any given fuel to detonate may either be increased or decreased as desired by the addition of a suitable compound to the combustion mixture, the amount required being very small in some cases.

La détonation ou le "cognage" qui caractérise la combustion dans les moteurs à benzine sous certaines conditions, est influencée premièrement par la composition chimique ou la structure du carburant et secondairement par la compression à laquelle le mélange combustible est soumis, par sa température, et par le point du cycle auquel l'allumage se produit, de même que par quelques autres facteurs de moindre importance, tels que la forme de la chambre de combustion et la situation de la bougie d'allumage (1, 8). Les principaux types de composés qui peuvent être utilisés comme carburants dans les moteurs à essence peuvent être classés dans l'ordre de leur tendance décroissante à détoner, comme suit (2, 8): Ethers, Paraffines, Oléfines, Naphthènes, Aromatiques et Alcools. La tendance de chaque carburant à détoner peut être augmentée ou diminuée suivant le désir, par l'addition d'un composé convenable au mélange de combustion, la quantité requise pour produire l'effet étant dans certains cas très faible.

Die Detonation oder das Klopfen (knock), welche die Verbrennung in Benzinmotoren unter gewissen Bedingungen kennzeichnet, ist zunächst von der chemischen Zusammensetzung oder Struktur des Brennstoffes beeinflusst, in zweiter Linie von der Kompression, dem das Verbrennungsgemisch ausgesetzt ist, von seiner Temperatur und von der Lage des Zündpunktes im Kreisprozess. In gleicher Weise hängt es noch von kleineren Faktoren ab, wie der Form des Verbrennungsraumes und der Lage der Zündkerze (1, 8). Die hauptsächlichsten Arten die als Motorbetriebsstoffe in Frage kommen, ordnen sich selbst in abnehmender Ordnung ihrer Fähigkeit zu klopfen, in folgender Weise (2, 8): Äther-Arten, Paraffine, Olefine, Naphtene, Stoffe der aromatischen Reihe und Alkohole. Die Neigung irgend eines gegebenen Betriebsstoffes zu detonieren, kann nach Bedarf erhöht oder erniedrigt werden, durch Hinzufügung einer passenden Verbindung zum Betriebsstoff. Die dazu notwendige Menge ist in manchen Fällen sehr gering.

La detonazione (Knock) che, in certe condizioni, caratterizza la combustione nei motori a essenza, è influenzata anzitutto dalla composizione chimica o struttura del carburante, e in secondo luogo dal grado di compressione della miscela, dalla sua temperatura, e dal momento in cui l'accensione avviene durante il ciclo. Essa dipende pure da altri fattori secondari, come la forma della camera di combustione e la posizione della candela (1, 8). I principali tipi di composti che possono adoperarsi come carburanti nei motori a essenza si possono disporre nell'ordine seguente graduandoli secondo la tendenza decrescente a detonare (2, 8): eteri, paraffine, olefine, nafteni, sostanze aromatiche, alcoli. La tendenza di un dato combustibile a detonare può essere accresciuta o diminuita a piacere aggiungendo alla miscela combustibile un adatto composto. La quantità di sostanza a ciò necessaria è in alcuni casi molto piccola.

RELATIVE EFFECTS OF SOME MISCELLANEOUS COMPOUNDS FOR SUPPRESSING DETONATION IN ENGINES

Aniline in concentration of 2% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (1, 3, 4). The values given below are, respectively, (*a*) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (*b*) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline.

Compound	Formula	(*a*) Wt. for given effect	(*b*) Rel. mol. effectiveness	Lit.
Aniline	$C_6H_5NH_2$	1	1	
Benzene	C_6H_6	9.8	0.085	(1)
Toluene	$C_6H_5CH_3$	8.8	0.112	(1)
Xylene	$C_6H_4(CH_3)_2$	8.0	0.142	(1)
Alcohol	C_2H_5OH	4.75	0.104	(5)
Ethyl iodide	C_2H_5I	1.55	1.09	(6)
Diethyl selenide	$(C_2H_5)_2Se$	0.214	6.9	(6)
Diphenyl selenide	$(C_6H_5)_2Se$	0.49	5.2	(6)
Diethyl telluride	$(C_2H_5)_2Te$	0.075	26.6	(6)
Diphenyl telluride	$(C_6H_5)_2Te$	0.139	22.0	(6)
Triphenylphosphine	$(C_6H_5)_3P$	3.08	0.91	(7)
Triphenylarsine	$(C_6H_5)_3As$	2.44	1.35	(7)
Triphenylstibine	$(C_6H_5)_3Sb$	1.56	2.42	(7)
Tetraethyl tin	$(C_2H_5)_4Sn$	0.66*	3.8*	(7)
Tetraethyl lead	$(C_2H_5)_4Pb$	0.0295	118	(3)
Tetraphenyl lead	$(C_6H_5)_4Pb$	0.080†	69.5†	(9)
Diphenyl diethyl lead	$(C_6H_5)_2$-$(C_2H_5)_2Pb$	0.041†	110†	(9)
Triethylbismuthine	$(C_2H_5)_3Bi$	0.135†	23.8†	(9)
Triphenylbismuthine	$(C_6H_5)_3Bi$	0.22†	21.5†	(9)
Nickel carbonyl	$Ni(CO)_4$	0.053†	35†	(9)
Dimethyl cadmium	$(CH_3)_2Cd$	1.23†	1.25†	(9)
Titanium tetrachloride	$TiCl_4$	0.64†	3.2†	(9)

* Values for tetraethyl tin in doubt because of preignition induced by the compound.

† These figures computed from the data of the original article, and converted to the aniline scale used for the other values in the table, on which tetraethyl lead is 118, instead of 100 as it is in the system of comparison used by the authors.

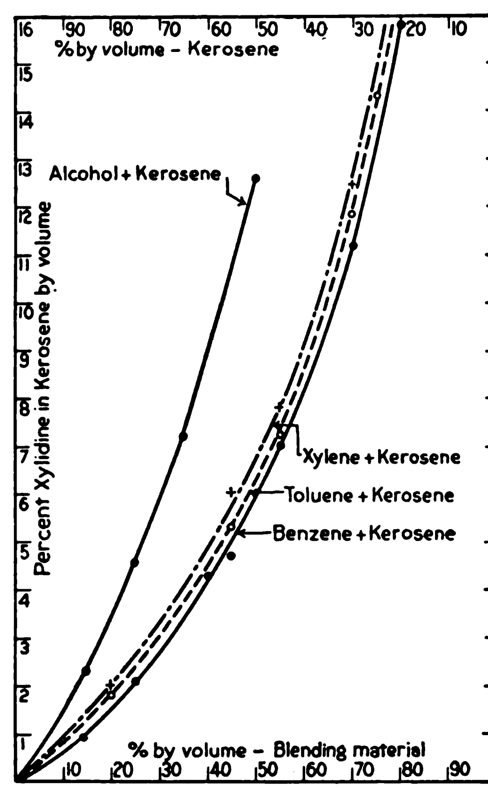
RELATIVE EFFECTS OF SOME COMPOUNDS OF NITROGEN FOR SUPPRESSING DETONATION IN ENGINES

Aniline in concentrations up to 3% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (4). The values given below are, respectively, (*a*) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (*b*) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline. Negative values are marked (−).

Compound	Formula	(*a*) Wt. for given effect	(*b*) Rel. mol. effectiveness
Aniline	$C_6H_5NH_2$	1	1
Cumidine	$(CH_3)_3C_6H_2NH_2$	0.96	1.51
Diphenylamine	$(C_6H_5)_2NH$	1.21	1.5
m-Xylidine	$(CH_3)_2C_6H_3NH_2$	0.92	1.4
Monomethylaniline	$C_6H_5NHCH_3$	0.83	1.4
Toluidine	$CH_3C_6H_4NH_2$	0.94*	1.22*
Amylaminobenzene	$C_5H_{11}C_6H_4NH_2$	1.53	1.15
Ethylaminobenzene	$C_2H_5C_6H_4NH_2$	1.14	1.14
Aminodiphenyl	$C_6H_5C_6H_4NH_2$	1.6	1.14
Methyl-*o*-toluidine(7)	$CH_3C_6H_4NHCH_3$	1.15	1.13
n-Butylaminobenzene	$C_4H_9C_6H_4NH_2$	1.44	1.11
n-Propylaminobenzene	$C_3H_7C_6H_4NH_2$	1.32	1.10
Monoethylaniline	$C_6H_5NHC_2H_5$	1.27	1.02
Mono-*n*-propylaniline	$C_6H_5NHC_3H_7$	1.95	0.75
Ethyldiphenylamine	$C_2H_5N(C_6H_5)_2$	3.65	0.58
Mono-*n*-butylaniline	$C_6H_5NHC_4H_9$	3.1	0.52
Diethylamine	$(C_2H_5)_2NH$	1.59	0.495
Di-*n*-propylaniline	$C_6H_5N(C_3H_7)_2$	7.15	0.27
Mono-isoamylaniline	$C_6H_5NHC_5H_{11}$	7.1	0.248
Diethylaniline	$C_6H_5N(C_2H_5)_2$	6.7	0.24
Dimethylaniline	$C_6H_5N(CH_3)_2$	6.2	0.21
Ethylamine	$C_2H_5NH_2$	2.4	0.20
Triethylamine	$(C_2H_5)_3N$	7.95	0.14
Triphenylamine	$(C_6H_5)_3N$	30.0	0.09
Ammonia	NH_3	2.0(−)	0.09(−)
Isopropyl nitrite	$C_3H_7NO_2$	0.085(−)†	11.5(−)†

* Average of *o*-, *m*-, and *p*-values.

† Approx. only. Organic nitrates and nitrites in general are inducers of detonation, the former being more effective than the latter, and the alkyl compounds much more effective than the aryl. Chlorine and bromine, as well as some of their compounds, induce detonation also.



Relative effect of hydrocarbons for suppressing detonations in engines (1, 5). Kerosene as fuel; xylidine as standard of effect upon detonation.

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(For a key to the periodicals see end of volume)

(1) Midgley and Boyd, *45*, 14: 589; 22. (2) Midgley, *244*, 7: 495; 20. (3) Midgley and Boyd, *45*, 14: 894; 22. (4) Boyd, *45*, 16: 893; 24. (5) Midgley and Boyd, *244*, 10: 451; 22. (6) Midgley, *45*, 15: 421; 23. (7) Boyd, *O.* (8) Ricardo, *381*, 11: 92; 21. (9) Charch, Mack and Boord, *45*, 18: 334; 26.

LUBRICANTS AND LUBRICATION

J. H. HYDE

For density, viscosity and other physical properties of lubricants, *see* p. 136.

JOURNAL BEARING FRICTION

In the following tables the value of the coefficient of friction of a journal bearing is given for different values of the quantity:

$$\frac{60\eta N}{P} = 60 \times \frac{\text{Absolute viscosity of lubricant at bearing temperature} \times \text{r. p. s.}}{\text{Pressure on bearing}},$$ where pressure on bearing = $$\frac{\text{Total load on bearing}}{\text{Length of bearing} \times \text{diameter of journal}}.$$

Coefficient of Kinetic Friction for Different Values of the Ratio $\frac{\text{Clearance}}{\text{Diameter}}$ (4)

$\frac{60\eta N}{P}$	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.
	1/1000		1/500		1/250		1/100	
100	0.005	0.006	0.0045	0.0025	0.0035	0.0032	0.003	0.010
250	0.0115	0.012	0.011	0.006	0.0095	0.0035	0.0075	0.010
500	0.018	0.024	0.017	0.012	0.016	0.0060	0.0115	0.0096
750	0.024	0.036	0.021	0.018	0.019	0.0090	0.0135	0.0092
1000	0.030	0.048	0.025	0.024	0.020	0.0125	0.0150	0.0090
1250	0.036	0.060	0.029	0.030	0.021	0.0158	0.0165	0.0090

Coefficient of Kinetic Friction (4)

$\frac{60\eta N}{P}$	100	200	300	400	500	600	700	800	900	1000	1100	1200
Stribeck white metal bearing 5.40 in. long....	0.0128	0.0190	0.0245	0.0290	0.0335	0.0370	0.0405	0.0435	0.0462	0.0482	0.0500	0.0512
Bronze bearing 9.06 in. long................	0.0085	0.0125	0.0156	0.0182	0.0205	0.0222	0.0240	0.0255	0.0270	0.0282	0.0295	0.0305
Hersey full bearing. $\frac{\text{Clearence}}{\text{Diameter}}$ = 0.04.......	0.0038	0.0055	0.0075	0.0092	0.0110	0.0130	0.0145	0.0165	0.0182	0.0200	0.0220	0.0238

Rupture of Lubricating Film

Values of $\frac{60\eta N}{P}$ for rupture of lubricating film in a journal bearing, for bearings of different clearances (4).

$\frac{60\eta N}{P}$	60	50	40	35	30	25	20	15	12	11
$\frac{\text{Diameter}}{\text{Clearence}}$ at rupture...	260	300	350	400	460	555	700	900	1200	1400

Effect of Various Lubricants on Static Friction

Coefficient of static friction between surfaces of mild steel and various metals when lubricated with various oils, for pressures ranging from 10 to 120 lb./in.^{2} and at a temperature of 16°C; "Deeley" Machine Tests (3).

Lubricant	Coefficient of static friction							
	Mild steel against							Hardened steel against Bronze*
	White metal	Axle steel	Cast iron	Wrought iron	Gun metal	"Stones" bronze	Aluminum	
Rape	0.109	0.137	0.102	0.136	0.155	0.124	0.111	0.080
Lard	0.118	0.110	0.133	0.125	0.155	0.117	0.100	0.082
Castor	0.138	0.121	0.131	0.136	0.166	0.121	0.126	0.109
FFF cylinder	0.165	0.147	0.179	0.159	0.177	0.128	0.137	0.120
Bayonne	0.185	0.157	0.214	0.185	0.207	0.158	0.145	0.132
Mobiloil BB	0.188	0.174	0.182	0.174	0.233	0.152	0.145	
Sperm	0.195	0.121	0.138	0.146	0.214	0.173	0.156	0.111
Mobil E								0.115
Victory red								0.117

* Average between 10 and 120 lb./in.^{2}

Coefficient of Kinetic Friction for Surfaces of Cast Iron and Steel When Lubricated with Various Oils

Pressure 30 lb./in.^{2}; 22° to 24°C. Variation of coefficient of kinetic friction with rubbing speed and quantity of stearic acid addition to lubricant. "Deeley" Type Machine (4).

Rubbing speed, ft. per min	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Mineral auto oil alone	0.26	0.23	0.21	0.19	0.17	0.15_5	0.14	0.12_5	0.115	0.11	0.105	0.105
+½ % stearic acid	0.105	0.090	0.080	0.075	0.070	0.065	0.060					
+2 % stearic acid	0.085	0.075	0.065	0.060	0.055	0.053	0.052	0.050	0.048	0.047	0.046	0.045

Effect of Additions to Bayonne Oil

Effect of additions of rape oil and of fatty acids to Bayonne oil (straight mineral). Coefficient of static friction between surfaces of hardened steel and bronze. "Deeley" Machine Tests. Pressure 10 to 120 lb./in.^{2} 16°C (2).

	For a neutral rape oil. No *free* fatty acid						For a rape oil containing 2.44 % *free* fatty acid						
Per cent of added oil	0	4	8.2	20.5	41.0	100	0	2	4	8.2	20.5	40.9	100
Coeff. of static friction	0.132	0.110	0.105	0.099	0.096	0.083	0.132	0.109	0.102	0.099	0.093	0.088	0.080

	For additions of oleic acid									
Per cent oleic acid added	0	0.20	0.40	0.80	1.50	2	10	40	80	100
Coeff. of static friction	0.132	0.102	0.097	0.092	0.088	0.087	0.086	0.085	0.079	0.075

Effect of Pressure on Coefficient of Static Friction (5)

Pressure between surfaces, lb./in.^{2}	8.6	17.3	26.0	36.6	43.3	52.0
Mild steel and cast iron with rape oil	0.205	0.200	0.203	0.208	0.218	0.229
Mild steel and gun metal with FFF cylinder oil	0.172	0.100	0.081	0.067	0.058	0.052
Mild steel and gun metal with sperm oil	0.020	0.029	0.036	0.045	0.053	0.061

Variation of Static Friction with Lubricant for Various Lubricants under Constant Pressure of 10 Lb./In.^{2} (5)

Mild steel against	Clock oil (HB)	Bayonne	Typewriter	Victory red	FFF cylinder	Manchester spindle	Castor	Sperm	Trotter (hard)	Olive	Rape	Valvoline cylinder
Cast iron	0.271	0.213	0.211	0.195	0.193	0.183	0.153	0.127	0.123	0.119	0.119	0.143
Gun metal	0.275	0.234	0.294	0.246	0.236	0.262	0.169	0.189	0.152	0.196	0.136	

LUBRICATING VALUE OF OILS UNDER CONDITIONS OF HEAVY LOADS AND TEMPERATURES UP TO 100°

Tests made on the Daimler-Lanchester Worm Gear Testing Machine at the National Physical Laboratory, England, show that the value of a straight mineral oil as a lubricant, when the load is great, diminishes rapidly above a certain critical temperature. It has been found by a very large number of tests under the same conditions of speed, load and supply of lubricant at a given temperature, that the efficiency of the worm gear in the testing machine remains remarkably constant at the load selected for the tests, and, as differences of efficiency could be determined to 0.1 % (absolute efficiency to 0.2 %), the efficiency-temperature values obtained give a valuable indication of the quality of the lubricant.

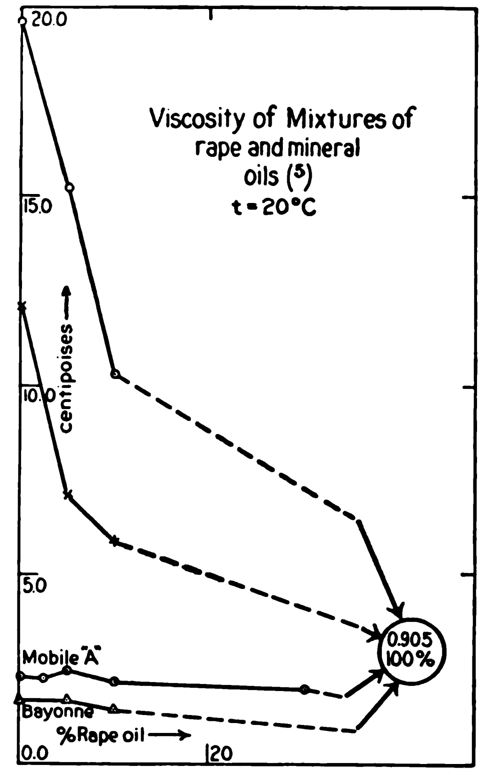
Effect of Temperature on Gear Efficiency

Variation of efficiency of power transmission by worm gear, with temperature of lubricant, for a straight mineral oil (Bayonne oil). This example is typical of all mineral oils (5).

°C	15 to 42	45	50	55	60	65	70
Gear efficiency, %	95.0	94.7	94.2	93.8	93.4	93.1	92.9

°C	75	80	85	90	95	100
Gear efficiency, %	92.8	92.7	92.6	92.5	92.5	92.4

The following critical temperatures were observed: Bayonne, 42°; FFF cylinder, 71°; Victory red oil, 50°; Mobiloil "A," 56°; Mobiloil "BB," 62°; lard, rape, castor and sperm, none observed. A small addition of fatty oil, fatty acid or graphite raises the critical temperature 10 to 20°.



LITERATURE

(For a key to the periodicals see end of volume)

(1) Hersey, *306*, **35**: 648; 23. (2) Hyde, *116*, **111**: 708; 21. (3) Hyde, National Physical Laboratory, England, *O*. (4) Wilson and Barnard, *46*, **14**: 682; 22. (5) *Report of the Lubrications and Lubricants Enquiry Committee*, Dept. of Scientific and Industrial Research, England, 1920.

TYPICAL ANALYSES AND PROPERTIES OF GASEOUS FUELS

E. R. Weaver

The hydrocarbons in natural gases and the hydrogen and saturated hydrocarbons in manufactured gases are usually determined by combustion, and the actual compounds present are not determined. The properties which affect the use of the gas as a fuel (heating value, specific gravity, air required for combustion and products formed by combustion) would be the same for a mixture of the composition stated by the analysis as for the mixture analyzed. For example, a mixture of one volume of hydrogen and one of ethane has the same values for these properties as two volumes of methane; and in an analysis of manufactured gas they would appear as methane. The "illuminants" of manufactured gas generally include all hydrocarbons present except those of the paraffin series. The first table gives the actual compositions of some typical gases; the second table gives analyses stated in the conventional manner. The same index letter in the two tables refers to the same gas.

Actual Composition

The last column of each series of hydrocarbons in which a number is entered includes higher homologs

Gas	Constituents of gas, % by volume															
	H_2	CO	Saturated hydrocarbons					Illuminants						Inerts		
			CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	C_2H_4	C_3H_6	C_4H_8	C_2H_2	C_6H_6	C_7H_8	CO_2	O_2	N_2
Natural gases Appalachian field A			90.7	3.8	3.3	0.8	0.4									1.0
B			84.7	9.4	3.0	1.3										1.6
C			80.4	8.7	4.1	4.0	1.3									1.5
D			44.7	7.9	21.3	9.9	16.2									1.0
Oklahoma E			74.7	13.0	6.0	1.5	0.8									4.0
Texas ("wet gas") F			50.6	3.1	2.4	8.4								*ca.* 1% He		34.5
Gas "F" after removal of gasolene G			54.8	3.3	2.6	0.8								*ca.* 1% He		37.5
Coal gas H	52.5	6.8	30.0	0.8	0.12	0.02		2.0	0.3	0.1	0.01	1.1	0.4	1.7	0.6	3.5
Carburetted water gas I	32.0	29.8	13.1	2.9	0.3			9.8	2.8	1.7		0.9	0.6	4.8		1.3

Composition Given by Conventional Methods of Analysis

Gas		Constituents of gas, % by volume									Specific gravity (air = 1)	Volume air per volume gas required for combustion	Heat of combustion kg-cal per l (1 atm., 15.5°C) to form liquid H_2O and gaseous CO_2 at 15.5°C	Products of combustion volumes per volume of gas			
		H_2	CO	CH_4	C_2H_6	C_3H_8	Illuminants	CO_2	O_2	N_2				CO_2	H_2O	N_2	Total
Natural gases	A			84.2	14.8					1.0	0.63	10.5	9.9	1.14	2.13	8.35	11.62
	B			79.1	19.3					1.6	0.66	10.8	10.2	1.18	2.16	8.57	11.91
	C			63.1	35.4					1.5	0.73	12.0	11.3	1.34	2.32	9.50	13.16
	D				38.8	60.2				1.0	1.33	20.9	20.0	2.58	3.57	16.35	22.68
	E			62.5	33.5					4.0	0.73	11.6	11.0	1.29	2.26	9.22	12.77
	F			23.0	41.5					35.5	0.91	9.2	8.7	1.06	1.70	7.60	10.36
	G			50.6	10.9					38.5	0.77	6.7	6.3	0.72	1.36	6.66	8.74
Kern Co., Calif.				78.6	10.3			9.7		1.4	0.70	9.2	8.7	1.09	1.88	7.33	10.30
Coal gas H		51.4	6.8	32.0			3.9	1.7	0.6	3.5	0.41	5.4	5.5	0.55	1.25	4.31	6.11
Carburetted water gas I		28.5	29.8	19.8			15.8	4.8		1.3	0.71	6.4	6.2	0.99	1.11	5.05	7.15
Coal and coke-oven gases																	
"700 BTU"		44.8	4.3	41.1			6.0	1.1	0.4	2.3	0.42	6.3	6.2	0.61	1.42	4.96	6.99
"600 BTU"		48.7	7.8	33.0			4.3	1.5	0.2	4.5	0.41	5.3	5.3	0.53	1.25	4.21	5.99
"550 BTU"		49.3	9.4	28.4			3.5	2.3	0.6	6.5	0.43	4.8	4.9	0.49	1.15	3.84	5.48
"500 BTU"		51.0	11.0	23.7			3.1	2.6	0.5	8.1	0.44	4.3	4.5	0.45	1.06	3.46	4.97
"450 BTU"		41.5	9.6	22.2			3.0	4.2	0.5	19.0	0.54	3.9	4.0	0.44	0.932	3.26	4.63
Carburetted water gas																	
"700 BTU"		31.2	28.2	20.2			15.3	2.0		3.1	0.65	6.1	6.2	0.89	1.08	4.82	6.79
"600 BTU"		34.8	30.6	15.0			11.5	4.2		3.9	0.65	5.1	5.3	0.80	0.93	4.08	5.81
"500 BTU"		40.4	32.7	10.5			8.0	5.1		3.5	0.61	4.1	4.5	0.68	0.81	3.29	4.78
"400 BTU"		45.2	36.5	5.2			4.0	6.0		3.1	0.59	3.2	3.6	0.58	0.66	2.55	3.79
"Blue" water gas		50.5	40.2	1.2			0.0	4.4		3.8	0.54	2.3	2.7	0.46	0.53	1.85	2.84
Oil gas																	
"800 BTU"		38.1	2.8	40.9			12.2			6.0	0.49	7.2	7.1	0.77	1.51	5.74	8.02
"700 BTU"		41.5	7.0	36.8			8.4	1.5		4.8	0.47	6.2	6.2	0.67	1.36	4.96	6.99
"600 BTU"		45.8	9.6	31.0			4.7	2.8		6.1	0.46	5.3	5.4	0.58	1.21	4.24	6.03
"550 BTU"		50.3	10.6	27.4			3.5	2.5		5.7	0.43	4.8	4.9	0.50	1.14	3.84	5.48
"500 BTU"		55.2	12.4	23.4			1.6	2.8		4.6	0.40	4.3	4.5	0.45	1.07	3.33	4.85
Producer gas																	
"175 BTU"		21.1	19.8	4.0				6.8		48.3	0.80	1.36	1.6	0.31	0.29	1.56	2.16
"150 BTU"		15.3	23.2	2.4				6.1		53.0	0.86	1.15	1.3	0.32	0.20	1.44	1.96
"125 BTU"		11.6	23.0	1.3				5.5		58.6	0.89	0.95	1.1	0.30	0.14	1.34	1.78
"100 BTU"		5.9	23.8	0.4				6.0		63.9	0.95	0.75	0.9	0.30	0.70	1.23	1.60
Blast furnace gas		1.2		27.2				8.0		63.6	1.01	0.68	0.8	0.35	0.01	1.18	1.54

ASPHALTS AND MINERAL WAXES

HERBERT ABRAHAM

Under this heading will be considered the following groups of substances: (1) Mineral waxes; (2) native asphalts; (3) asphaltites; (4) asphaltic pyrobitumens; and (5) pyrogenous asphalts. These five groups are members of the class "Bituminous substances," the first three falling within the group "Bitumens," the fourth within the group "Pyrobitumens," and the fifth within the group "Pyrogenous residues."

NOMENCLATURE

The definitions which follow show the relationship between these respective groups of substances.

Bituminous Substances.—A class of native and pyrogenous substances containing bitumens or pyrobitumens, or resembling them in their physical properties. [This definition includes bitumens, pyrobitumens, pyrogenous distillates (pyrogenous waxes and tars) and pyrogenous residues (pitches and pyrogenous asphalts).]

Bitumen.—A generic term applied to native substances of variable color, hardness and volatility; composed of hydrocarbons substantially free from oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *fusible* and largely *soluble* in carbon disulfide; the distillates, fractionated between 300 and 350°C, yield *considerable sulfonation residue.* [This definition includes petroleums, native asphalts, native mineral waxes and asphaltites.]

Pyrobitumen.—A generic term applied to native substances of dark color; comparatively hard and non-volatile; composed of hydrocarbons, which may or may not contain oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *infusible*, and relatively *insoluble* in carbon disulfide. [This definition includes the asphaltic and non-asphaltic pyrobitumens and their respective shales.]

Mineral Wax.—A term applied to a species of bitumen, also to certain pyrogenous substances; of variable color, viscous to solid consistency; having a *characteristic luster* and *unctuous feel;* comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing *considerable crystallizable paraffins;* sometimes associated with mineral matter, the non-mineral constituents being easily fusible and soluble in carbon disulfide. [This definition is applied to crude and refined native mineral waxes, also to pyrogenous waxes. Crude native mineral waxes include ozokerite, etc. Refined native mineral waxes include ceresine (refined ozokerite) and montan wax (extracted from lignite or pyropissite by means of solvents). Pyrogenous waxes include the solid paraffins separated from non-asphaltic and mixed-base petroleums, peat, tar, lignite tar and shale tar].

Asphalt.—A term applied to a species of bitumen, also to certain pyrogenous substances of *dark color*, variable hardness, comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing relatively little to no crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *fusible*, and largely soluble in carbon disulfide; the distillate, fractionated between 300 and 350°C, yields *considerable sulfonation residue.* [This definition is applied to native asphalts and pyrogenous asphalts. Native asphalts include asphalts occurring naturally in a pure or fairly pure state, also asphalts associated naturally with a substantial proportion of mineral matter, sometimes termed "rock asphalts." The associated mineral matter may be sand, sandstone, limestone, clay, shale, etc. Pyrogenous asphalts include residues obtained from the distillation, blowing, etc., of petroleums (*e.g.*, *residual oil*, produced by the dry distillation of non-asphaltic petroleum, the dry or steam distillation of mixed-base petroleum and the steam distillation of asphaltic petroleum, *blown asphalt*, produced by blowing air through heated residual oils, *residual asphalts*, produced by the steam distillation of mixed-base and asphaltic petroleum, *sludge asphalt*, produced from the acid sludge obtained in the purification of petroleum distillates with sulfuric acid, etc., also from the pyrogenous treatment of wurtzilite (*e.g.*, *wurtzilite asphalt*, produced by depolymerizing wurtzilite in closed retorts).]

Asphaltite.—A species of bitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, substantially free from oxygenated bodies and crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *difficultly fusible* and largely soluble in carbon disulfide; the distillation residue, fractionated between 300 and 350°C, yields *considerable sulfonation residue.* [This definition includes *gilsonite* (conchoidal fracture and characteristic brown streak on porcelain), *glance pitch* (conchoidal to hackly fracture and black streak) and *grahamite* (conchoidal to hackly fracture and black streak).]

Asphaltic Pyrobitumens.—A species of pyrobitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, *substantially free from oxygenated bodies;* sometimes associated with mineral matter, the non-mineral constituents being *infusible* and largely *insoluble* in carbon disulfide. [This definition includes *elaterite* (characteristic rubbery nature and brown streak), *wurtzilite* (conchoidal to hackly fracture; brown streak; depolymerizes on heating, becoming fusible and soluble), *albertite* (conchoidal to hackly fracture; brownish black streak; depolymerizes partially on heating), *impsonite* (hackly fracture; black streak; does not depolymerize on heating) and the *asphaltic pyrobituminous shales.*]

CHARACTERISTICS

The distinguishing physical and chemical characteristics of the substances enumerated above are given in the following table.

THERMAL PROPERTIES

An asphalt of 2.12 specific gravity gave the following values for the *thermal conductivity* in joule $cm^2\ sec^{-1}$ $(°C, cm^{-1})^{-1}$: 0°, 0.0061; 10°, 0.0065; 20°, 0.0070; 30°, 0.0074 (Poensgen, *98*, **56**: 1653; 12. **60**: 27; 16).

According to Kinoshita (*380*, **39**: 497; 16) the *specific heat* of asphalt is 0.22 g-cal per g per °C.

Genus	Species	Member	Sp. gr. at 25°C (of non-mineral matter)*	Penetration at 25°C†	Susceptibility factor‡	Fusibility °C§	Fixed carbon‖	Solubility in carbon disulfide¶	Non-mineral matter insoluble in carbon disulfide¶	Mineral matter¶	Carbenes**	Soluble in 88° naphtha††	Oxygen in non-mineral matter‡‡	Paraffin scale§§	Sulfonation residue‖‖	Saponifiable matter¶¶
	Petroleums															
	Native mineral waxes	Ozokerite	0.85–1.00	5–10	80	60 to 95	½–10	95–100	0–1	0–5	0–3	75–95	0–2	50–90	90–100	0–2
		Montan wax	0.90–1.00	5	100	75 to 95	2–10	98–100	0–2	0–2	0–2	80–100	3–6	0–10	0–10	50–80
Bitumens	Native asphalts	Cont'g less than 10% mineral matter	0.95–1.12	0–350	15–100	15 to 165	1–25	60–98	0–40	0–10	0–5	25–95	0–2	0–5	90–100	0–2
		Cont'g more than 10% mineral matter	0.95–1.15	0–150	30–100	15 to 175	5–25	Tr.–90	0–25	10–95	0–5	Tr.–85	0–2	0–5	90–100	0–2
	Asphaltites	Gilsonite	1.05–1.10	3	100	120 to 175	10–20	90–100	0–1	Tr.–1	0–½	40–60	0–2	0–Tr.	85–95	Tr.
		Glance pitch	1.10–1.15	5	100	120 to 175	20–30	95–100	0–1	Tr.–5	0–1	20–50	0–2	0–Tr.	85–95	Tr.
		Grahamite	1.15–1.20	0	100	175 to 320	30–55	45–100	0–5	Tr.–50	0–80	Tr.–50	0–2	0–Tr.	80–95	Tr.
Pyrobitumens	Asphaltic pyrobitumens	Elaterite	0.90–1.05	Rubbery		Inf.	2–5	10–20	70–90	Tr.–10	Tr.–2	5–10	1–5	0–Tr.	80–90	Tr.–15
		Wurtzilite	1.05–1.07	5		Inf.	5–25	5–10	80–95	Tr.–10	Tr.–2	Tr.–2	0–2	0–Tr.	90–98	Tr.
		Albertite	1.07–1.10	0		Inf.	25–50	2–10	85–98	Tr.–10	Tr. 2	Tr. 2	0–3	0–Tr.	90–98	Tr.
		Impsonite	1.10–1.25	0		Inf.	50–85	1–6	90–99	Tr.–10	Tr.–2	Tr.–2	0–3	0–Tr.	90–98	Tr.
		Asphaltic pyrobituminous shales	1.50–1.75	0		Inf.	2–25***	Tr.–3	15–70	30–85	0–Tr.	0–Tr.	0–3	Tr.–3	90–98	Tr.
	Non-asphaltic pyrobitumens															
Pyrogenous distillates	Pyrogenous waxes															
	Tars															
Pyrogenous residues	Pyrogenous asphalts	Residual oils	0.85–1.05	100–350		–20 to 25	2–10	98–100	0–½	0–½	0–1	80–99	0–3	0–15	90–100	Tr.–5
		Blown petroleum asphalts	0.90–1.07	25–200	8–40	25 to 200	5–20	95–100	0–5	0–½	0–10	50–90	2–5	0–10	90–100	Tr.–2
		Residual asphalts	1.00–1.17	0–150	40–60	25 to 110	5–40	85–100	0–15	0–1	0–30	25–85	0–2½	0–5	90–100	0–2
		Sludge asphalts	1.05–1.20	0–150	40–60	25 to 110	5–30	95–100	0–5	0–1	0–15	60–95	3–7	0–½	80–95	0–2
		Wurtzilite asphalt	1.04–1.07	5–10	30–40	65 to 150	5–25	98–100	0–½	Tr.–2	0–2	50–80	0–2	0–Tr.	90–95	Tr.
	Pitches															

* Am. Soc. Testing Materials, Tentative Standards, **1922**: 473, 476. † *Ibid.*, **1921**; 728. ‡ Abraham, *66*, **11**: 683; 11. § Am. Soc. Testing Materials, Standards, **1921**: 739. ‖ *Ibid.*, **1921**: 766. ¶ Anon., *66*, **23 I**: 761; 23. ** Anon., *66*, **23 I**: 754; 23. *B68*, p. 526. †† *B68*, p. 527. ‡‡ Am. Soc. Testing Materials, Tentative Standards, **1921**: 779. §§ *B68*, p. 536. ‖‖ *B68*, p. 537. ¶¶ *B68*, p. 547.
*** Calculated on mineral-free basis.

BITUMINOUS MATERIALS

John M. Weiss and Charles R. Downs

TARS, PITCHES AND DISTILLATES

This section deals with those species of pyrogenous residues known as "tars," together with the products of tar distillation, *i.e.*, "residuals" or "pitches," and "distillates" or "tar oils." These are highly complex materials formed by the pyrogenetic decomposition of various organic materials, so that a particular member or sub-member may vary widely in its physical characteristics.

In the first section are given certain so-called constants in terms of ranges for the various materials. These give general information as to the nature of the various materials. The results are expressed in terms of arbitrary tests which depend upon rigid adherence to details of manipulation; the test methods are those generally used in the United States. The ranges given have been taken partly from the literature, but for the most part from private communications from various commercial concerns dealing with the products (2, 5, 6, 11, 16, 18, 19), and certain U. S. Government laboratories (4, 10). Freak results caused by some unusual procedure in the production of a given material have been eliminated so as to make the ranges representative of the materials as they are ordinarily encountered in industry.

In addition, there are reported the available more or less absolute constants that have been determined. As the materials in a given narrow class vary in ordinary tests, so they also vary in these "absolute" constants between samples in the same class; the accuracy of the figures is only moderate, but, in general, adequate to the commercial need which caused the determinations to be made. Blanks indicate that no authentic results are available. Single figures mean that the test of a single sample only could be obtained.

Table 1.—Tars

The figures in Table 1 apply to water-free tar. In attempting to identify tars, it is advisable to distill them and test the oils (*See* Table 3.) Methods of testing are given by Weiss (22). η is Engler viscosity, sec for 100 cm³; % insol. is the % organic insoluble in C_6H_6 and C_7H_8.

Genus	Species	Member	Sub-member	$d_{15.5}^{15.5}$	η	% insol.	% fixed carbon	% ash	% tar acids
Tars	Coal tars	Bituminous coal	Coke oven	1.15–1.26	30–100	3–17	14–40	0–0.5	1–4
			Horizontal gas retort	1.25–1.33	150–650	16–40	15–40	0–0.5	1–4
			Inclined gas retort	1.23–1.24	300	15–20	15–40	0–0.5	4–6
			Vertical gas retort	1.12–1.16	25–50	2–5½	15–30	0–0.5	5–11
			Low temperature processes	0.95–1.12	25–50	0–7	5–15	0–1.5	10–30
			Blast furnace	1.15–1.30	80	10–25	10–30	10–15	5–10
			Gas producer	1.12–1.20	100–α	5–25	10–35	0–25	3–9
		Cannel coal		0.945		0.2		0.1	9.0
		Lignite		0.85–1.05		0–2	5–20	0–1	5–20
	Petroleum tars	Carburetted water gas		1.06–1.15	25– 50	0.2–5.0	10–20	0–0.5	0
		Oil gas		0.95–1.10	25	0–2.0	10–25	0–0.5	0
	Wood tars	Hardwood		1.10–1.21	50	0–5.0	5–20	0–1.0	5–15
		Softwood (pine tars)		1.05–1.15	65	0–7.5	5–15	0–1.0	10–40
	Miscellaneous tars	Bone		0.95–1.05	28	0–5.0	3–15	0–0.5	0.3–40
		Shale		0.85–0.95		0–2.0	5–10	0–1.0	0–2
		Peat		0.90–1.05		0–3.0	5–15	0–1.0	5–15

$d_{15.5}^{15.5}$ of 235–315° fraction (A. S. T. M. distn.): Coke oven, 1.02–1.05; horizontal and inclined gas retort, 1.02–1.04; vertical gas retort, 1.00–1.01; bone tar, 0.950.

Table 2.—Pitches

Method of testing, Weiss (22). The M. P. range given is about the maximum in which they have been known to occur commercially

Genus	Species	Member	Sub-member	Cube M. P.	$d^{15.5}_{15.5}$	% Insol.	% fixed carbon	% ash
Tar pitches	Coal tar pitches	Bituminous coal	Coke oven	30–150	1.20–1.35	8–50	17–60	0–0.5
			Horizontal gas retort	30–100	1.25–1.40	30–55	36–65	0–0.5
			Inclined gas retort	30–100	1.25–1.35	28–37	37–45	0–0.5
			Vertical gas retort	30–150	1.15–1.30	6–30	15–40	0–0.5
			Low temperature processes	30– 90	1.00–1.26	2–15	8–22	0–3.0
			Blast furnace	30–100	1.20–1.30	15–35	10–30	10–20
			Gas producer	30–100	1.20–1.35	15–40	25–45	0–2
		Cannel coal		55	1.067	5.3	14.2	0.2
		Lignite coal		30–115	1.05–1.20	3–16	10–40	0–1.0
	Petroleum tar pitches	Carburetted water gas tar		30–150	1.10–1.25	2–25	25–45	0–0.5
		Oil gas tar		30–150	1.15–1.30	2–30	20–35	0–0.5
	Wood tar pitches	Hardwood		40–100	1.20–1.30	5–70	15–35	0–1.0
		Softwood		40–100	1.10–1.20	2–60	10–25	0–1.0
	Miscellaneous tar pitches	Bone		30–125	1.10–1.20	1–20	15–25	0–0.5
		Shale						
		Peat		35–125	1.05–1.15	0– 5	10–30	0–1.0
Stearine pitch	Fatty acids				0.90–1.10	0– 5	5–35	0–5
Rosin pitch				50–100	1.08–1.15	0– 2	10–20	0–1

Table 3.—Distillates

Method of testing: Tar acids, Weiss (22); *d*, *n*, sulfonation residue, Bateman (3)

	d^{60}_{60}				n^{60}_{D}				Sulfonation residue				Tar acids
	235–55°	255–75°	275–95°	295–315°	235–55°	255–75°	275–95°	295–315°	235–55°	255–75°	275–95°	295–315°	Total oil distillate
Coke oven	1.01 –1.04	1.02 –1.06	1.03–1.08	1.06–1.09	1.588–1.609	1.590–1.618	1.594–1.628	1.608–1.635	0–3.5	0–5.0	0–5	0–5	1–12
Horizontal gas retort	1.01 –1.025	1.02 –1.04	1.04–1.07	1.06–1.09	1.580–1.596	1.590–1.602	1.598–1.614	1.610–1.628	0–1.5	0–1.5	0–3	0–3	5–20
Inclined gas retort	1.005–1.015	1.01 –1.035	1.03–1.06	1.04–1.06	1.574–1.593	1.577–1.596	1.586–1.608	1.594–1.623	0.5–4.5	1–7	2–8	3–8	14
Vertical gas retort	1.000–1.01	1.01 –1.025	1.02–1.05	1.04–1.06	1.53 –1.575	1.579	1.587–1.594	1.600–1.612	4–6	5–7	5–6	4–6	20–30
Blast furnace	0.94 –0.95	0.95	0.94–0.96	0.96–0.98	1.523	1.530	1.534	1.543	17	21	21	19	30
Gas producer	0.95			0.98	1.50 –1.52				16				10
Lignite	0.96	0.96	0.96–0.97	0.97–0.98	1.520	1.528	1.534	1.542	21	25	28	29	30–50
Carburetted water gas	0.96 –1.01	0.965–1.03	0.97–1.07	0.98–1.08	1.558–1.598	1.562–1.602	1.572–1.622	1.578-1.630	0–11	0–13	0–16	0–17	0
Oil gas	0.93	0.93	0.93	0.94–0.95	1.533	1.533	1.533	1.530–1.540	26.0	32.0	38.0	34.0	0
Hardwood	0.98	0.97			1.500	1.495			7	9			47
Softwood	0.98 –0.99	0.99	0.99	0.99	1.505	1.514	1.523	1.533	2	3–4	4–5	4.0	15
Bone	0.92	0.94	0.95	0.94					12.0	7.4	3.0	0.0	0.5

Low temperature coke oven shows tar acids in total oil distillate 20–50.

Coefficients of Cubical Expansion

$\alpha = \frac{10^6(V_2 - V_1)}{V_1(t_2 - t_1)}$. In each case an average figure for use is suggested, with figures showing the maximum deviation of individual samples from the average suggested. For special cases, reference to the original articles is recommended ([3, 8, 13, 21, 23]). For effect of solids in creosote oil, *see* ([8, 13]).

Material	Range °C	α per °C	Max. dev. ±
Water gas tars	15–80	655	25
Vertical retort coal tars	15–80	640	10
Coke oven coal tars	15–80	575	25
Horizontal gas retort coal tars	15–80	550	60
Low temperature coal tars	15–85	760	15
Coal tar and heavy oils (when liquid)	15–80	760	40
Water gas tar and heavy oils	15–60	770	20
Low temperature tar and heavy oils	15–85	760	30
Coal tar middle oils	15–60	800	20
Gas drip (holder oils)	15–60	1000	50
Coal tar and water gas tar pitches	15–250	460	40
Low temperature tar pitches	15–85	660	40

Flash Points

These represent open cup results ([3, 5, 6, 18]).

40°C M. P.	Coal tar pitch	145°C
60°C M. P.	Coal tar pitch	211°C
Coal tar creosotes		70–75°C
Low temperature tars		100°C ± 10°C

Specific Heat—G-Cal G^{-1} Deg.$^{-1}$ C

Coal tars—from 0.35 (±.05) at 40°C to 0.45 (±.05) at 200°C. Coal tar oils—0.34 (±.04) at 15°–90°C (([3]) and private communications).

Latent Heat of Vaporization

Coal tar oils ([24])

Temperature range, °C	Heat of vaporization, g/cal g^{-1}
199–249	84.8
249–296	81.0
296–345	85.1
345–392	73.3
392–438	65.1
438–488	63.1

Viscosity ([3, 13.5, 15, 20])

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EXPLOSIONS AND GASEOUS EXPLOSIVES

William A. Bone and Donald T. A. Townend

IGNITION TEMPERATURE

The ignition temperature of a gaseous mixture is the temperature at which the heat lost by conduction, etc., is more than counterbalanced by the rate at which it is developed by the reaction, the combustion thus becoming self-propellant. This temperature is a function not only of the gaseous mixture employed but also of the means used for heating it. Also, there is often a short "pre-flame" period, during which the combustion is autogenous, but without any actual appearance of flame.

Experimental Methods

A. Mixture passed through tube held at known temperature.
B. Mixture rapidly admitted to hot bulb at known temperature. Pre-flame "lag" sometimes determined by this method.
C. Bulb containing mixture heated rapidly to definite temperature.
D. Mixture passed through small reservoir while temperature was raised until flame at exit tube ran back into it.
E. Constituent gases heated separately in concentric tubes, gas from inner tube being then passed into gas in outer tube. In most recent methods pre-flame "lag" has been controlled.
F. Constituent gases heated separately and mixed in open away from surface contact.
G. Mixture adiabatically compressed and temperature calculated from final volume.
H. Mixture adiabatically compressed and temperature calculation based on final pressure experimentally determined. Correct temperature lies between the values calculated by methods G and H.
I. Glass vessel within an iron one, each containing a constituent gas. Glass vessel broken at definite temperature.
J. Small drop of inflammable liquid dropped into air or oxygen maintained at a known temperature.
K. Soap bubble blown with mixture touched by hot wire at known temperature.

Pressure = 1 atm. unless otherwise noted.

H_2

Method A (41); *cf.* (7, 9, 10, 16, 17)		Method B (4)		(24)
t°C*	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$	
605	—	550	—	For 15% H_2 in air, 590° in 375 cm³ vessel and 625° in 9 cm³ vessel. For 60% H_2 in air, 620° in 375 cm³ vessel and 712° in 9 cm³ vessel.
605	H_2	552–559	H_2	
611	$4H_2$			
617	$7H_2$	560–570	$3H_2$	
604	O_2	530–532	$1\frac{1}{2}O_2$	
599	$2\frac{1}{2}O_2$			
594	$4O_2$	552–553	$4N_2$	
589	$4\frac{1}{2}O_2$	560–595	$\frac{1}{2}CO_2$	
584	$7O_2$	562–592	$3CO_2$	

* All at $P = 300$ mm.

Method C (18); *cf.* (6, 9)		Method D (13)	Method F (42)
t°C	$2H_2 + O_2 +$		
589	—	650° — $2H_2 + O_2$	642° — $2H_2 + O_2$
560	N_2		
543	$2N_2$		
577	$3N_2$		
609	$4N_2$		

Method E (50, 52, 58); *cf.* (21, 43) : L = lag in sec; (a) = H_2 in O_2; (b) = H_2 in air

L	(a)	(b)	L	(a)	(b)	L	(a)	(b)	L	(a)	(b)
½	625	630	2	615	619	5	597	602	10	582	585
1	622	625	3	607	613	7	589	592	15	573	577

Influence of Pressure on Ignition Temperature of H_2 in Air

Method E (50, 52, 58) : L = lag in sec; P in mm

P* / L	75	100	200	400	600	760	1000	1200	1520
½	513	524	558	598	622	630	632	630	628
1	511	521	554	592	614	620	623	621	619
2	509	519	549	581	601	606	609	609	608
3			545	576	592	595	600	600	599

* For P = 7 atm. the ignition temp. = 611° for 0.5 sec lag.

Method G (50, 51, 58); *cf.* (20, 26, 28)		Method H (37)		Method I (36)	
t°C*	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$
521	—	410†	*ca.* $4N_2$	412	H_2
544	H_2			433	$2H_2$
581	$2H_2$	For 53% H_2 in air, 460°†		397.5	$\frac{1}{2}O_2$
501	O_2			407	O_2
481	$3O_2$				
459	$7O_2$				
439	$15O_2$			Method K (31, 33)	
540	*ca.* $4N_2$				
468	*ca.* $3O_2 + 16N_2$				

* Calc. using γ = 1.4.
† Calc. using γ = 1.32 to allow for cooling losses during compression.

$H_2 + Cl_2$

For $Cl_2 + H_2$ by method A (9), 430°–440°; method C (9), 240°–270°; in dark, 190° (11).

H_2S

For $2H_2S + 3O_2$ by method A (9), 315°–320°; method C (9), 250°–270°. For H_2S, by method E (21), in O_2, 220°–235°; in air, 346°–379°.

NH_3

By method E (21), in O_2, 700°–860°. By method not stated (22), in air, 780°.

CO

Method B (4): M = $2CO + O_2$				Method E (43); *cf.* (21)
t°C	M+	t°C	M+	For CO in O_2, 665° with ½ sec lag; 624° with 10 sec lag
645–650	CO	650–657	$4N_2$	For CO in air, 725° with ½ sec lag; 685° with 10 sec lag
630–650	4CO	695–715	$3CO_2$	Method B (24) 20–70% in air, 610°
650–680	O_2			
For method A and C *cf.* (9); for method D (13); for method G (19); for method K (31)				

CH_4 Methane

$CH_4 + 2O_2$, by method A (9), 650°–730°; by method C (9), 606°–650°. By method D (13), 656°–678°.

By method B (4), $CH_4 + 2O_2$ at 600°–650°; $5CH_4 + 2O_2$ at 640°–660°; 10% CH_4 by vol. in air at 730°–790°. (First observation of lags prior to explosion.) Method B* (23, 24, 40). % = % CH_4 in air; V_{15} = temp. in 15 cm³ vessel, V_{275} in 275 cm³ vessel and V_{81} in 81 cm³ vessel.

%	V_{15}	V_{275}	%	V_{15}	V_{275}	%	V_{81}	%	V_{81}
3	737	680	10	750	710	2	711	8.8	707
6.5	736	675	12	765	710	3	700	10	714
8.0	735	680	16	807	750	5.9	695	11.8	724
						7.0	697	14.4	742

* The explosion occurs after certain definite time lags.

Method E (43), *cf.* (21). For CH_4 in O_2, ½ sec lag, 665°; 10 sec lag, 624°. For CH_4 in air, ½ sec lag, 725°; 10 sec lag, 685°. Method E (50, 52, 58). For CH_4 in air. P = mm pressure; L = lag in sec.

P / L	100	200	400	600	760	1520	2280	3800	5320
0.5							705	675	653
0.6	815	788	765	753	746	722			
1	804	768	747	737	728	711	695	666	644
2	782	733	717	712	715	690	680	652	633
3	—	715	702	696	694	676	667	640	624

Method E (58). For CH_4 in O_2. P = mm pressure; L = lag in sec.

P / L	75	100	200	400	600	760
0.5	727	728	732	720	696	670
0.6	715	716	721	715	688	666
1	694	695	697	692	675	657
2	667	665	660	652	645	641
3		651	643	636	631	629
10		633	621	611	604	602

By method G (58), $CH_4 + 3O_2$, 340°; $CH_4 + 5O_2$, 345°; $CH_4 + 15O_2$, 377°; 7½% CH_4 in air, 428°.

C_2H_2 Acetylene

By method E (21), in O_2, 400°–440°; in air, 406°–440°. By method B (24), for 45–55% C_2H_2 in air, 335°; 20% in air, 400°; 10% in air, 500°.

C_2H_4 Ethylene

For $C_2H_4 + 3O_2$, method C (9), 530°–606°. By method B (24), for 4.5–6.5% C_2H_4 in air (vol. vessel = 275 cm³), 487°. By method E (21), for C_2H_4 in O_2, 500°–519°; in air, 542°–547°. *Cf.* (9), method A; (13), method D; (31), method K.

C_2H_6 Ethane

By method B (47). % = % C_2H_6 in air (vol. vessel = 85 cm³)

%	1.9	2.3	4.05	4.85	5.7	8.15	10.60
t°C	594	571	560	555	550	540	534

For C_2H_6, method A, *cf.* (9); method D (13). By method C (9), for $C_2H_6 + 3.5O_2$, 530°–606°. By method B (24), for 4–8% C_2H_6 in air (275 cm³ vessel), 560°.

C_3H_8 Propane

By method D (13), in O_2, 545°–548°. By method E (21), in O_2, 490°–570°. Method B (47), vol. of vessel = 85 cm³

% C_3H_8 in air	1.25	2.50	3.05	4.90	6.50	7.85
t°C	588	552	544	525	516	514

C_4H_{10} *n*-Butane

Method B (47), vol. of vessel = 85 cm³

% *n*-C_4H_{10} in air	1.25	2.00	2.60	3.65	4.85	7.65
t°C	569	545	531	515	502	489

C_4H_{10} Isobutane

For *iso*-C_4H_{10} by method D (13), in O_2, 545°–550°.

C_5H_{12} *n*-Pentane

For 2–3% C_5H_{12} in air, 512° by method B (24). For 6.7% in air, 320°–336° by method H (37). Method B (47), vol. of vessel = 85 cm³.

% C_5H_{12} in air	1.5	2.15	2.75	3.75	5.30	7.65
t°C	548	532	520	502	486	476

C_6H_6 Benzene

Method	B	J			K
Lit.	(24)	(30)	(38)	(45)	(31, 33)
	In air	In O_2	In O_2	In air	
	5%, 587°	566°	570	490	

C_6H_{14} *n*-Hexane

By method H (37), for 6.7% in air, 300°–306°.

C_7H_{16} *n*-Heptane

By method H (37), for 6.7% in air, 285°; (39) 5% in air, 280°(39).

C_8H_{18} *n*-Octane

By method H, for 6.7% in air, 275° (37); 280° (39).

Petroleum

Method	B	J				K
Lit.	(24)	(30)			(27)	(31, 33)
	In air		In O_2	In air	In air	
	2.2% 481°	Texas Borneo Mexico	256° 269° 274°	387° 380° 424°	Borneo 400°	

C_2H_6O Ethyl Alcohol

Method	B (in air)			J		
Lit.	(24)	(34)*		(30)	(38)	(45)
	27–38% 450°	2%, 515–520° 3%, 505°	4%, 455–500° 5%, 480–495°	395°‡ 518°†	355°‡	360°†

* Sub-ignition temp.
† In air.
‡ In O_2.

$C_4H_{10}O$ Ether

In air by method A (32), 190°; method B (35), 185°–193°; method J (30), 347°. In O_2 by method J (30), 190°.

By method B* (34), for 4.8% in air, 178°–184°; for 4.1%, 179°–185°; for 3.5%, 180.5°–188°. By method H (39), for 6.6% in air, 212°. Method K, *cf.* (31, 33).

* Giving sub-ignition temp. with incomplete combustion.

CS_2

Method E (48)

In O_2, °C	132	128	123	118	114	110	107
In air, °C	156	151	145	138	130	124	120
Lag in sec	0.5	1	2	3	5	7	10

By method B (5), for $CS_2 + 10O_2$ at P = 750 mm, 160° with 1–2 sec lag. At P = 300 mm and with 15 sec lag, for $CS_2 + 5O_2 + 5N_2$, 155°; for $CS_2 + \frac{1}{2}O_2 + 8N_2$, 290°. By method F (42), in O_2, 236°. By method H (39), for 12.5% in air, 253°.

C_2N_2 Cyanogen

By Method E (21), in O_2, 803°–818°

Miscellaneous

(a) = acetone, (b) = paraffin, (c) = turpentine, (d) = creosote oil, (e) = palm oil, (f) = aldehyde, (g) = aniline, (h) = toluene, (i) = xylene, (j) = methyl alcohol, (k) = amyl alcohol, (l) = anthracene, (m) = naphthalene.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Method	B* ‡	J†	J	J*	J*	?*	?*
Lit.	(34)	(30)	(30, 45)	(27)	(27)	(22)	(22)
	4%, 500° 8%, 500°	251°	275°*† 240°*	550°	400°	380°	530°

	(h)	(i)	(j)	(k)	(l)	(m)
Method	J†	?*	J†	J†	J†	J†
Lit.	(38, 30)	(22)	(38)	(38)	(38)	(38)
	563° 516°	500°	500°	315°	472°	500°

* In air.
† In O_2.
‡ Satd. at 15°, 505°.

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(30) Moore, *54*, **36**: 109; 17. (31) McDavid, *4*, **103**: 1003; 17. (32) Alilaire, *34*, **168**: 729; 19. (33) White and Price, *4*, **115**: 1248; 19. (34) White and Price, *4*, **115**: 1462; 19. (35) McClelland and Gill, *117*, **16**: 109; 20. (36) Fiesel, *7*, **97**: 158; 21. (37) Tizard, *411*, **37**: 381; 21. (38) Wollers and Emcke, *Krupp's Monatsheft*, 1921. (39) Tizard and Pye, *3*, **44**: 79; 22.

(40) Mason and Wheeler, *4*, **121**: 2079; 24. (41) Mitscherlich and Reuter, *93*, **121**: 53; 22. (42) Wartenburg and Kannenberg, *7*, **105**: 205; 23. (43) Dixon, *398*, **68**: 1; 23. (44) Tauss and Schulte, *98*, **68**: 574; 24. (45) Jentzsch, *98*, **68**: 1150; 24. (46) Ormandy, *358*, **10**: 335; 24. (47) Mason and Wheeler, *4*, **125**: 1869; 24. (48) Dixon, *70*, **44**: 305; 25. (49) David, *133*, **1925**; 303.

(50) Dixon, *133*, **1925**; 303. (51) Dixon and Harwood, *398*, **1925**. (52) Dixon and Higgins, *398*, **69**: 19; 25. (53) Parr, *45*, **17**: 1215; 25. (54) Coward and Wheeler, Safety in Mines Research Board, *Paper* No. **8**; 25. (55) Naylor and Wheeler, *Ibid.* No. **9**; 25. (56) Tizard and Pye, *3*, **1**: 1094; 26. (57) Pignot, *34*, **182**: 376; 26. (58) Dixon, Harwood and Higgins, *83*, preprint, 1926. (59) Dixon and Russell, *4*, **75**: 600; 99.

ELECTRICAL IGNITION

In the case of electrical ignition and probably also in contact with direct flame or with an incandescent wire, ionization of the gas is an important factor. In the case of electric spark ignition, attempts have been made to determine experimentally the minimum igniting current or spark energy. Unfortunately, however, quantitative values are not easily determined owing to experimental difficulties. Consequently, much of the experimental evidence is of a contradictory nature, so that the part played by ionization in determining the least energy required to inflame a given explosive mixture remains an unknown factor. Representative curves showing least igniting currents are given in Figs. 1 to 4.

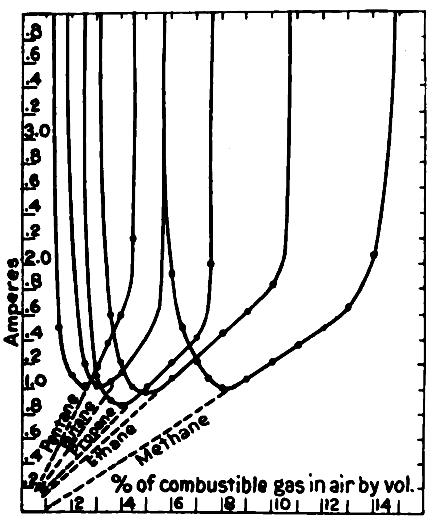

FIG. 1.—Least igniting currents for mixtures in air of members of the paraffin series, using break-sparks. Iron poles. 100 volts (8).

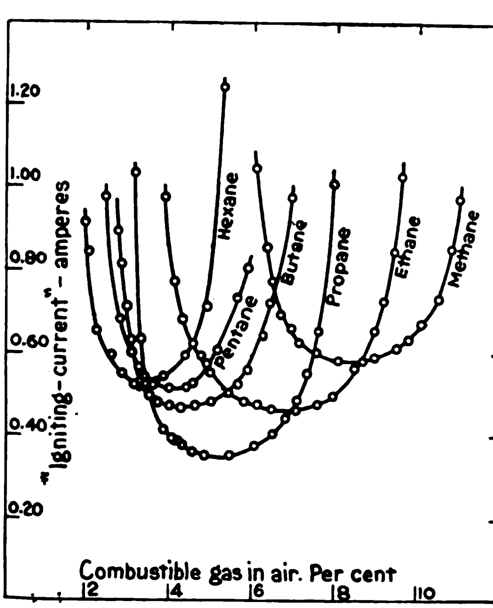

FIG. 2.—Least igniting currents for mixtures in air of members of the paraffin series, using impulsive electrical discharges (33).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Thornton, *80*, **44 I**: 145; 12. **46 II**: 112; 13. (2) Thornton, *115*, **94**: 348; 13. *396*, **120**: 295; 13. *121*, **70**: 62; 13. (3) Thomson, *63*, **14**: 11; 13. (4) Thornton, *121*, **71**: 1012; 13. (5) Thornton, *5*, **90**: 272; 14. (6) Thornton, *121*, **73**: 822; 14. (7) Thornton, *5*, **91**: 17; 14. (8) Thornton, *3*, **28**: 734; 14. (9) Hauser, *329*, **1916**; 521.

(10) Thornton, *5*, **92**: 9; 16. (11) Thornton, *5*, **92**: 381; 16. (12) Morgan, *115*, **102**: 427; 16. (13) Morgan, *121*, **76**: 536; 16. *399*, **111**: 66; 16. (14) Thornton, *399*, **112**: 504; 16. (15) Sastry, *4*, **109**: 523; 16. (16) Wheeler, *4*, **111**: 130; 17. (17) Wheeler, *4*, **111**: 411; 17. (18) Wright, *4*, **111**: 643; 17. (19) Paterson and Campbell, *67*, **31**: 168; 19.

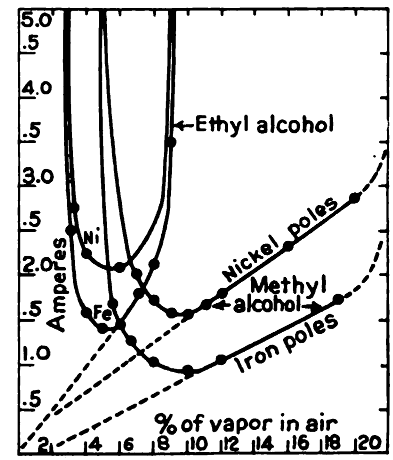

FIG. 3.—Influence of the nature of the pole on the least igniting current for mixtures of methyl or ethyl alcohol vapor with air, using break-sparks. Iron and nickel poles. 100 volts (5).

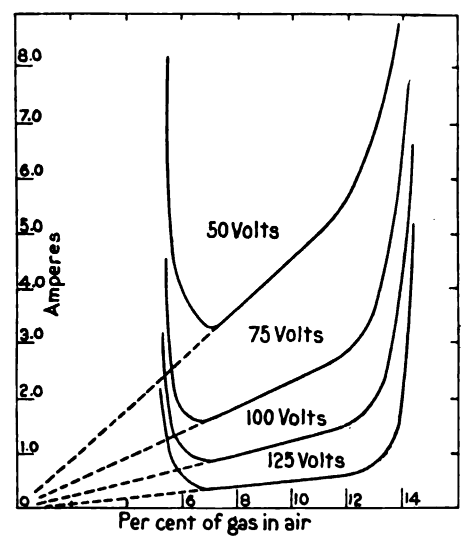

FIG. 4.—Influence of current voltage on the least igniting current for methane-air mixtures, using break-sparks. Iron poles, continuous current (5).

(20) Thornton, *3*, **38**: 613; 19. (21) Morgan, *4*, **115**: 94; 19. (22) Thornton, *3*, **40**: 345; 20. (23) Thornton *3*, **40**: 450; 20. (24) Wheeler, *4*, **117**: 903; 20. (25) Morgan, *3*, **41**: 462; 21. (26) Morgan and Wheeler, *4*, **119**: 239; 21. (27) Thornton, *400*, **11**: 524; 22. (28) Jones, Morgan and Wheeler, *3*, **43**: 359; 22. (29) Thornton, *135*, **1923**; 469.

(30) Morgan, *4*, **123**: 1304; 23. (31) Morgan, *3*, **43**: 968; 23. (32) Thornton, *46*, **62**: 481; 24. (33) Wheeler, *4*, **125**: 1858; 24. (34) Wheeler, *4*, **127**: 14; 25. (35) Morgan, *3*, **49**: 323; 25. (36) Thomson, *The Conduction of Electricity through Gases*, London, Cambridge Univ. Press, 1903. (37) Morgan, *Principles of Electric Spark Ignition in Internal Combustion Engines*. London, Lockwood, 1923. (38) Wheeler, Safety in Mines Research Board, *Paper* No. **20**; 26. (39) Bone and Weston, *5*, **110**: 615; 26.

PRE-FLAME CONDITION

(40) Kirkby, *3*, **7**: 223; 04. (41) Kirkby, *3*, **13**: 289; 07. (42) Kirkby, *5*, **85**: 151; 11. (43) Lind, *78*, **21**: 177; 12. (44) Finch and Cowln, *5*, **111**: 257; 26.

LIMITS OF INFLAMMABILITY

The limits are given in volume % and apply to atmospheric conditions of temperature and pressure unless otherwise stated. The first value in the limits column is the lowest lower limit, and the second the highest higher limit of the experimentally found values, which usually agree within a few tenths of 1%.

Abbreviations

E_v	Explosion in closed vessel of volume v, cm^3 generally stated.
Fl_D	Downward propagation of flame.
Fl_H	Horizontal propagation of flame.
Fl_U	Upward propagation of flame.
Atm.	Nature of atmosphere.
Exper. condn.	Experimental conditions.
Tb_x	Tube whose diameter = x cm.
$Sat._x$	Gases saturated with H_2O vapor at x°.
$P_{x\,at.}$	Pressure, x atmospheres.
$P_{x\,mm}$	Pressure, x mm Hg.

All temperatures are in °C.

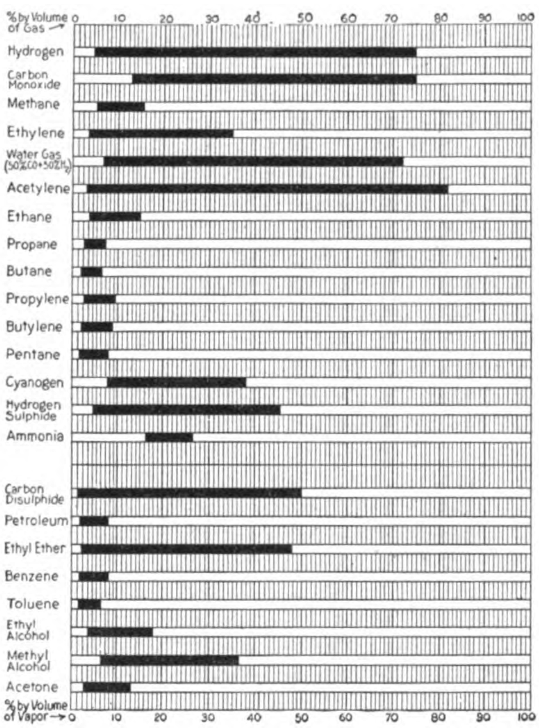

FIG. 4a.—Limits of inflammability of mixtures of gases and vapors with air.

H_2

Atm.	Limits	Exper. condn.	Lit.
O_2..........	9.4–91.0	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
	9.0–93.3	100°	
Air..........	9.2–65.0	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
	9.2–68.5	100°	
Air..........	9.0–62.8	15° Fl_H, Tb_4, dried by P_2O_5	(12)
	9.0–68.6	100°	
$CO_2:O_2$......	11.7–68.4	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
79:21........	11.4–69.4	100°	
Air..........	5.0–72.0	Glass, $Tb_{7.5}$, Fl_U	(14)
Air..........	10.0–	E_{2000}	(18)
Air..........	9.5–66.3		(19)
Air..........	9.45–66.4	E_{110}, Sat.	(23)
Air..........	9.73–63.6	$Tb_{1.4}$, Fl_D	(25)
O_2..........	5.45–94.7	$Sat._{15-18}$	(28)
Air..........	8.7 –	E_{100}, Fl_D	(34)
O_2..........	8.7 –	E_{100}, Fl_D	(34)
Air..........	9.05–68.6	$P_{2-3\,at.}$ E_{1940}, Fl_D	(36)
	9.28–68.0	$P_{5-6\,at.}$ E_{1940}, Fl_D	(36)
	9.47–67.5	$P_{10\,at.}$ E_{1940}, Fl_D	(36)
Air..........	4.1 –	$E_{170\,000}$, Fl_U, $Sat._{17-18}$	(39)
Air..........	4.1 –60.0		(51)
Air..........	10 –66.0	E_v	(52)
Air..........	–74.2	$Sat._{room}$ 15 l vessel	(56)
Air..........	9.4 –65.3	E_{120}	(60)
O_2..........	9.1 –91.7	E_{120}	(60)
$O_2:N_2$....... 40.1:59.9	9.2 –81.2	E_{120}	(60)
$O_2:N_2$....... 56.2:43.8	9.2 –86.4	E_{120}	(60)
Air..........	9.46–64.5	Glass pipette	(73)
	9.42–65.9	Glass bulb	(73)
	10.78–59.8	(20°) Iron tube	(73)
	9.27–67.5	100°	
	8.98–72.2	200°	
	8.62–79.1	300°	
Air..........	4.15–75.0	Fl_U, $Tb_{7.5}$	(74)
	6.50–	Fl_H, $Tb_{7.5}$	(74)
	8.8 –74.5	Fl_D, $Tb_{7.5}$	(74)
Air..........	9.40–71.5	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	9.2 –	50°	
	8.8 –73.5	100°	
	8.3 –	150°	
	7.9 –76.0	200°	
	7.5 –	250°	
	7.1 –79.0	300°	
	6.7 –	350°	
	6.3 –81.5	400°	

H_2S

Atm.	Limits	Exper. condn.	Lit.
Air..........	4.5 –19.0		(51)
Air..........	5.9 –27.2	Fl_H, Tb_6	(72)
Air..........	4.30–45.5	Fl_U, $Tb_{7.5}$	(74)
	5.30–35.0	Fl_H, $Tb_{7.5}$	(74)
	5.85–21.3	Fl_D, $Tb_{7.5}$	(74)

NH_3

Atm.	Limits	Exper. condn.	Lit.
Air..........	16.2–27.0	E_{500}, sphere	(34)
O_2..........	15 –80	Found by altering burner mixture	(45)
Air..........	16.1–26.6	Fl_U, Tb_5, 18°	(65)
	18.2–25.5	Fl_H, Tb_5, 18°	(65)
	22.1–23.3	Fl_D, Tb_5, 70°	(65)
	21.0–24.6	Fl_D, Tb_5, 90°	(65)
	15.0–28.7	Fl_U, Tb_5, 140°	(65)
	17.0–27.5	Fl_H, Tb_5, 140°	(65)
	19.9–26.3	Fl_D, Tb_5, 140°	(65)
	14.0–30.4	Fl_U, Tb_5, 250°	(65)
	15.9–29.6	Fl_H, Tb_5, 250°	(65)
	17.8–28.2	Fl_D, Tb_5, 250°	(65)
	13.0–32.2	Fl_U, Tb_5, 350°	(65)
	14.7–31.1	Fl_H, Tb_5, 350°	(65)
	16.0–30.0	Fl_D, Tb_5, 350°	(65)
	12.3–33.9	Fl_U, Tb_5, 450°	(65)
	13.5–33.1	Fl_H, Tb_5, 450°	(65)
	14.4–32.0	Fl_D, Tb_5, 450°	(65)

NH_3.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
	17.1–26.4	Fl_U, $Tb_{7.5}$, 18°	(65)
	17.4–26.3	Fl_H, $Tb_{7.5}$, 18°	(65)
O_2..........	15.3–79.0	Fl_U, Tb_5, 18°	(65)
	16.7–79.0	Fl_H, Tb_5, 18°	(65)
	14.8–	Fl_H, Tb_5, 250°	(65)
	15.8–	Fl_D, Tb_5, 250°	(65)
	12.6–	Fl_H, Tb_5, 450°	(65)
	13.5–	Fl_D, Tb_5, 450°	(65)
	14.8–	Fl_U, $Tb_{7.5}$, 18°	(65)
	15.6–	Fl_H, $Tb_{7.5}$, 18°	(65)
	17.3–	Fl_D, $Tb_{7.5}$, 18°	(65)

CO

Atm.	Limits	Exper. condn.	Lit.
O_2..........	15.4 –94.1	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	14.4 –94.8	100°	
Air..........	14.1 –74.8	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	13.0 –77.6	100°	
$CO_2:O_2$ 79:21 ..	21.6 –73.1	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	20.0– 75.1	100°	
Air..........	13.0 –75.0	Fl_U, $Tb_{7.5}$	(14)
	15.9 –74.5	Fl_H, Tb_4	(14)
Air..........	19.1 –61.7	$Tb_{0.6}$	(17)
	38.0 –57.0	$Tb_{0.3}$*	(17)
	16.4 –	P_{430}	(17)
	18.6 –	P_{130}	(17)
	27.9 –	P_{85}	(17)
	14.2 –	400°	(17)
	9.3 –	470°	(17)
	7.4 –	575°	(17)
Air	16.0 –		(18)
Air..........	17.3 –74.8		(19)
Air..........	16.5 –75.0	E_{110}, Sat.	(23)
Air..........	14.5 –	100° } E_{100}, Fl_D, $Sat._{15-18}$	(34)
O_2..........	15.7 –	100°	(34)
Air..........	15.9 –72.9	$P_{1at.}$, E_{1940}	(36)
	18.4– 62.0	$P_{10at.}$, Fl_D	(36)
Air..........	12.5 –	$E_{170\ 000}$, Fl_D, $Sat._{17-18}$	(39)
Air..........	12.6 –70.0		(51)
Air..........	15.0 –73.0	$Sat._{room}$	(52)
Air..........	–74.2	15 l vessel	(56)
Air..........	15.55–71.0	E_{120}	(60)
O_2..........	16.63–93.6	E_{120}	(60)
$O_2:N_2$			
37.8:63.2....	15.85–83.6	E_{120}	(60)
50.8:49.2....	15.85–87.7	E_{120}	(60)
Air..........	15.75–68.9	Glass pipette	(73)
	15.4 –71.6	Glass bulb	(73)
	15.8 –63.8	(20°) } Iron tube	(73)
	14.05–69.6	100°	
	13.80–76.6	200°	
Air..........	12.8 –75.0	Fl_U, $Tb_{7.5}$	(74)
	13.6 –	Fl_H, $Tb_{7.5}$	(74)
	15.3 –70.5	Fl_D, $Tb_{7.5}$	(74)
Air..........	16.3 –70.0	17 ± 3° } Fl_D, $Tb_{2.5}$	(78)
	15.7 –	50°	
	14.8 –71.5	100°	
	14.2 –	150°	
	13.5 –73.0	200°	
	12.9 –	250°	
	12.4 –75.0	300°	
	12.0 –	350°	
	11.4 –77.5	400°	

* No mixture can propagate flame through glass $Tb < 0.23$.

CH_4 Methane

Atm.	Limits	Exper. condn.	Lit.
O_2..........	6.0 –57.3	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	5.7 –57.4	100°	
Air..........	5.7 –13.2	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	5.5 –13.2	100°	
	5.8 –12.8	15° } Fl_H, Tb_4, dried over P_2O_5	(12)
	5.8 –13.6	100°	
$CO_2:O_2$			
79:21........	8.7 –11.9	15° } Fl_H, Tb_4, $Sat._{17.5}$	(12)
	8.5 –12.2	100°	
Air..........	5.0 –13.0	Fl_U, $Tb_{7.5}$	(14)
	6.0 –11.0	Fl_D, $Tb_{7.5}$	(14)
Air..........	6.0 –	$E_{2\ 000}$	(18)
Air..........	6.4 –12.8		(19)
Air..........	6.1 –12.8	E_{110}, Sat.	(23)
	6.3 –	Fl_D, $Tb_{6.2}$	(23)
Air..........	5.6 –	E_V, sphere 16 cm diam., central ignition	(30)
Air..........	6.0 –	100° } Fl_D, E_{100}, $Sat._{15-18}$	(34)
O_2..........	6.25–	100°	
Air..........	6.0 –13.0	$P_{1at.}$ } Fl_D, E_{1940}	(36)
	6.6 –14.0	$P_{10at.}$	
$N_2:O_2:CO_2$			
81:19........	5.5 –13.5	Limits given are for explosion in a large steel bomb	(33)
31:19:50	8.0 –11.3		
83:17........	5.7 –11.8		
40:17:43	8.3 –8.7		
85:15........	5.9 –9.6		
64:15:21	7.3 –7.5		
87:14........	6.3 –7.1		
85:13:2......	6.6 –6.8		
O_2..........	5.99–		
$O_2:N_2$			
80:20........	5.95–		
60:40........	5.90–		
40:60........	5.82–		
30:70........	5.77–	E_V, sphere 16 cm diam.	(38)
25:75........	5.76–	E_V, sphere 16 cm diam.	(38)
20:80........	5.78–		
19:81........	5.84–		
13.4:86.6....	6.41–		
13:87........	6.63–		
Air..........	5.3 –	$E_{170\ 000}$, $Sat._{15-17}$	(39)
Air..........		Ignition at:	
	5.6 –14.8	Center } E_V, 16 cm sphere	(41)
	5.4 –14.8	Top	
	6.0 –13.4	Bottom	
	5.4 –14.3	Fl_H, E_V, Tb_6	(41)
$O_2:N_2$			
20.9:79.1....	5.60–14.8		(42)
19.2:80.8....	–12.9		
18.3:81.7....	–11.9		
17.0:83.0....	5.80–10.6		
15.8:84.2....	5.83–8.96		
14.9:85.1....	6.15–8.36		
13.9:86.1....	6.35–7.26		
13.5:86.6....	6.50–6.70		
13.2:86.8....	*		
Air..........	5.76–	Fl_D	(43)
	5.56–	Fl_H	(43)
	5.52–	Fl_U	(43)

* No mixture capable of propagating flame.

CH_4 Methane.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
Air..........	4.9 –	Fl_U	
	5.7 –	Fl_D } Box, 5.75 ft., cube	(47)
	5.5 –	Fl_H	
Air..........	5.0 –	Fl_U, E_{2900}	(47)
	–13.9	Fl_D, Tb_{30}	(47)
	–15.4	Fl_U, Tb_{30}	(47)
	5.5 –13.2	Fl_D, E_{100}	(47)
Air..........	5.46–	25°, E_{100}	(48)
	4.98–	200°, E_{700}	(48)
	4.75–	300°, E_{100}	(48)
	4.55–	400°, E_{100}	(48)
	3.75–	500°, E_{100}	(48)
	5.5 –	$P_{1-\text{sat.}}$, E_{100}	(48)
Air..........	5.6 –14.8		(51)
Air..........	5.5 –14.5		(52)
Air..........	6.00–13.4	20°, Fl_D, E_V	(55)
	5.45–13.5	100°, Fl_D, E_V	(55)
	5.20–13.6	150°, Fl_D, E_V	(55)
	5.05–13.9	200°, Fl_D, E_V	(55)
	4.60–14.0	250°, Fl_D, E_V	(55)
	4.40–14.3	300°, Fl_D, E_V	(55)
	4.15–	350°, Fl_D, E_V	(55)
	4.00–14.7	400°, Fl_D, E_V	(55)
	3.65–15.4	500°, Fl_D, E_V	(55)
	3.35–16.4	600°, Fl_D, E_V	(55)
	3.25–18.8	700°, Fl_D, E_V	(55)
	–23.6	750°, Fl_D, E_V	(55)
	–29.0	800°, Fl_D, E_V	(55)
	6.00–13.0	P_{760}, Fl_D, E_V	(55)
	6.05–13.2	P_{1250}, Fl_D, E_V	(55)
	–13.4	P_{2100}, Fl_D, E_V	(55)
	6.20–13.6	P_{2900}, Fl_D, E_V	(55)
	6.25–	P_{3350}, Fl_D, E_V	(55)
	–13.8	P_{3750}, Fl_D, E_V	(55)
	6.40–14.1	P_{4650}, Fl_D, E_V	(55)
Air..........	–15.4	15 l vessel, Sat. room	(56)
$O_2:N_2$			
13.7:86.3....	6.4 –6.9	Fl_H, $Tb_{2.5}$	
17.0:83.0....	6.1 –8.9	Fl_H, $Tb_{2.5}$	
21.0:79.0....	5.8 –13.3	Fl_H, $Tb_{2.5}$	(58)
33.0:67.0....	5.8 –25.1	Fl_H, $Tb_{2.5}$	
50.0:50.0....	5.8 –38.8	Fl_H, $Tb_{2.5}$	
66.0:34.0....	5.8 –47.5	Fl_H, $Tb_{2.5}$	
O_2..........	5.7 –59.2	Fl_H, $Tb_{2.5}$	(58)
Air..........	6.05–12.1	E_{120}	(60)
O_2..........	6.39–52.1	E_{120}	(60)
$O_2:N_2$			
45.2–54.8....	6.26–29.7	E_{120}	
62.2–37.8....	6.30–38.6	E_{120}	(60)
86.3–13.7....	6.44–47.8	E_{120}	
Air..........	6.12–13.6	Glass pipette	(73)
	5.82–13.6	Glass bulb	(73)
	6.25–12.8	(20°)	
	6.02–13.9	100° } Iron tube	(73)
	5.91–14.1	200°	
	5.80–14.1	300°	
Air..........	5.35–14.9	Fl_U, $Tb_{7.5}$	(74)
	5.40–14.0	Fl_H, $Tb_{7.5}$	(74)
	5.95–13.4	Fl_D, $Tb_{7.5}$	(74)
Air..........	6.30–12.9	17 ± 3°	
	6.20–	50° } Fl_D, $Tb_{2.5}$	(78)
	5.95–13.7	100°	
	5.75–14.1	150°	

CH_4 Methane.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
	5.5 –14.6	200°	
	5.30–	250°	
Air..........	5.10–15.5	300°	
	4.95–	350° } Fl_D, $Tb_{2.5}$	(78)
	4.80–16.6	400°	
	4.55–	450°	
Air..........	5.4 –14.1	E_V, $Tb_{1.5}$	(75)
Air +			
0.8% $C_2H_2Cl_2$	7.35–10.2		
0.8% $C_2H_2Cl_4$	7.15– 9.2		
1.0% C_2HCl_5	5.95–10.3		
20% $C_2H_2Cl_2$.	*		(75)
5.5% C_2HCl_3.	*		
8.5% CCl_4...	9.0 –9.9		
12.2% CCl_4..	*		

* No propagation of flame.

See also p. 191.

C_2H_2 Acetylene

Atm.	Limits	Exper. condn.	Lit.
Air..........		Fl_H, $Tb_{0.05}$	(13)
	7.7 –10.0	Fl_H, $Tb_{0.08}$	(13)
	5.0 –15.0	Fl_H, $Tb_{0.2}$	(13)
	4.5 –25.0	Fl_H, $Tb_{0.4}$	(13)
	4.0 –40.0	Fl_H, $Tb_{0.6}$	(13)
	3.5 –55.0	Fl_H, $Tb_{2.0}$	(13)
	3.1 –62.0	Fl_H, $Tb_{3.0}$	(13)
	2.9– 64.0	Fl_H, $Tb_{4.0}$	(13)
Air..........	2.8 –65.0	Continuous propagation,	(18)
O_2..........	2.8 –93.0	large vol.	
Air..........	3.8 –40.0		(19)
Air..........	3.0 –82.0	Fl_D, $Tb_{7.5}$	(14)
Air..........	3.35–52.3	E_{110}, Sat.	(23)
Air..........	1.53–58.7	Fl_D, $Tb_{1.4}$	(25)
Air..........	2.82–51.7	Fl_D, E_{100}	(46)
	–73.0	Fl_U, E_{2800}	(46)
	2.98–	Fl_{U-D}, E_{2800}	(46)
	2.53–	Fl_U, E_{28317}	(46)
	2.87–	Fl_D, E_{25317}	(46)
Air..........	3.0 –46.0		(51)
Air..........	3.0 –73.0		(52)
Air..........	3.4 –52.5	E_{120}	(60)
O_2..........	3.4 –90.0	E_{120}	(60)
$O_2:N_2$			
40.5:59.5....	3.4 –74.4	E_{120}	
58.0:42.0....	3.4 –82.4	E_{120}	(60)
78.5:21.5....	3.4 –87.4	E_{120}	
Air..........	2.68–	Glass pipette	(73)
	2.39– Upper limit indefinite	Glass bulb	(73)
	3.12–	(20°)	
	1.95–	100° } Iron tube	(73)
	1.95–	200°	
Air..........	2.60–80.5	Fl_U, $Tb_{7.5}$	(74)
	2.68–78.5	Fl_H, $Tb_{7.5}$	(74)
	2.78–71.0	Fl_D, $Tb_{7.5}$	(74)
Air..........	2.90–55.0	17 ± 3°	
	2.83–59.0	50°	
	2.68–65.0	100°	
	2.52–73.0	150° } Fl_D, $Tb_{2.5}$	(78)
	2.39–81.0	200°	
	2.30–	250°	
	2.19–	300°	

C_2H_4 Ethylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	4.0 –22.0	Fl_U, $Tb_{7.5}$	(14)
Air..........	4.1 –14.6	E_{110}, Sat.	(23)
	3.4 –	Fl_D, $Tb_{6.2}$, Sat.	(23)
Air..........	5.7 –17.5		(51)
Air..........	3.8 –14.2	E_{120}	(60)
O_2..........	4.0 –62.0	E_{120}	(60)
$O_2:N_2$			
40.4:59.6....	4.0 –47.7	E_{120}	(60)
74.7-25.3....	4.0 –56.4	E_{120}	
Air..........	3.4 –14.1	Fl_H, $Tb_{2.5}$	(62)
	3.6 –13.7	Fl_D, $Tb_{2.5}$	(62)
	3.2 –25.6	Fl_U, $Tb_{2.5}$	(62)
Air..........	3.52–	Glass pipette	(73)
	3.34–	Glass bulb	(73)
	3.69–	(20°) Iron tube	
	3.22–	100° Iron tube	(73)
	3.40–	200° Iron tube	
Air..........	3.02–34.0	Fl_U, $Tb_{7.5}$	(74)
	3.20–23.7	Fl_H, $Tb_{7.5}$	(74)
	3.33–15.5	Fl_D, $Tb_{7.5}$	(74)
Air..........	3.45–13.7	17 ± 3°	
	3.35–	50°	
	3.20–14.1	100°	
	3.10–	150° Fl_D, $Tb_{2.5}$	(78)
	2.95–14.9	200°	
	2.85–15.7	250°	
	2.75–17.9	300°	
	2.60–	350°	
	2.50–	400°	

C_2H_6 Ethane

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.10–	Center ignit. E_V, sphere 16 cm diam.	(30)
Air..........	3.10–10.7		(51)
Air..........	2.5 –5.0		(52)
Air..........	3.3 –10.6	Fl_H	(58)
Air..........	3.9 –9.6	$Tb_{2.5}$	(60)
O_2..........	3.9 –46.2	$Tb_{2.5}$	(60)
$O_2:N_2$			
37.4:63.6....	3.80–21.9	E_{120}	
59.5:40.5....	3.90–33.6	E_{120}	(60)
74.7:25.3....	3.80–39.7	E_{120}	
Air..........	3.12–15.0	Fl_U, $Tb_{7.5}$	(74)
	3.15–12.9	Fl_H, $Tb_{7.5}$	(74)
	3.26–10.2	Fl_D, $Tb_{7.5}$	(74)

C_3H_6 Propylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.18–9.7	Fl_U, $Tb_{7.5}$	(74)
	2.22–9.3	Fl_H, $Tb_{7.5}$	(74)
	2.26–7.4	Fl_D, $Tb_{7.5}$	(74)

C_3H_8 Propane

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.15–	Center ignit. E_V, sphere 16 cm diam.	(30)
Air..........	2.17–7.35		(51)
Air..........	2.4 –7.3	Fl_H, $Tb_{2.5}$	(58)

C_4H_8 Butylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.70–9.0	Fl_U, $Tb_{7.5}$	(74)
	1.75–9.0	Fl_H, $Tb_{7.5}$	(74)
	1.80–6.3	Fl_D, $Tb_{7.5}$	(74)

C_4H_{10} *n*-Butane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.60–	Center ignit. E_V, sphere 16 cm diam.	(28)
Air..........	1.55–5.7		(51)
Air..........	1.9– 6.5	Fl_H, $Tb_{2.5}$	(58)

C_5H_{12} *n*-Pentane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.1 –		(18)
Air..........	1.35–	E_V, sphere 16 cm diam.	(30)
Air..........	2.4 –4.9	E_{110}, Sat.	(23)
Air..........	1.35–4.5		(51)
Air..........	1.6 –5.4	Fl_H, $Tb_{2.5}$	(58)
Air..........	1.42–8.0	Fl_U, $Tb_{7.5}$	(74)
	1.44–7.45	Fl_H, $Tb_{7.5}$	(74)
	1.48–4.64	Fl_D, $Tb_{7.5}$	(74)
Air..........	1.53–4.5	17 ± 3°	
	1.50–	50°	
	1.44–4.75	100°	
	1.39–4.90	150° Fl_D, $Tb_{2.5}$	(78)
	1.34–5.05	200°	
	1.30–	250°	
	1.22–5.35	300°	

C_5H_{12} Isopentane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.30–	Center ignit. E_V, sphere 16 cm diam.	(30)

C_6H_6 Benzene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.5 –	E_{2000}	(18)
Air..........	1.4 –4.7	E_{2000}	(21)
Air..........	2.65–6.5	E_{110}	(23)
	1.4–	Fl_D, $Tb_{6.2}$	(23)
Air..........	1.5 –8.0		(51)
Air..........	2.6 –7.2	E_{120}	(60)
O_2..........	2.6 –30.1	E_{120}	(60)
$O_2:N_2$			
40.5:59.5....	–15.5	E_{120}	
58.0.42.0....	2.6 –21.0	E_{120}	(60)
78.5:21.5 ...	–27.5	E_{120}	
Air..........	1.41–7.45	Fl_U Wide tube	(64)
	1.46–5.55	Fl_D Wide tube	

C_6H_{14} Hexane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.3–	E_{2000}	(18)

C_7H_8 Toluene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.3 –	E_{2000}	(18)
Air..........	1.4 –	E_{2000}	(21)
Air..........	1.27–6.75	Fl_U Wide tube	(64)
	1.28–4.60	Fl_D Wide tube	

C_7H_{16} Heptane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.1–	E_{2000}	(18)

C_8H_{18} Octane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.0–	E_{2000}	(18)

Petroleum

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.4 –4.9	E_{110}	(23)
	1.1 –	Fl_D, $Tb_{6.2}$	(23)
Air..........	2.94–8.22	E_V, 60° fraction	(40)
Air..........	1.9 –5.3	Fl_D, E_{100}	(48)
	1.5 –6.4	Fl_U, E_{100}	(48)
	1.50–	23°	(48)
	1.42–	200°	(48)
	1.22–	300°	(48)
	1.02–	400°	(48)
Air..........	1.5 –6.0	E_{2300}	(51)
Air..........	1.8 –5.15	E_{120}	(60)
O_2..........	1.9 –28.8	E_{120}	(60)

Petroleum.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
O_2:N_2			
44.0:56.0....	1.8 -14.1	E_{120}	
59.5:40.5....	2.1 -19.2	E_{120}	(60)
74.7:25.3....	1.9 -28.8	E_{120}	

CH_4O Methyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	5.5 -21.0		(51)
Air..........	7.8 -18.0		(21)
Air..........	6.0 -		(18)
Air..........	7.05–36.5	Fl_U Wide tube	(64)
	7.45–26.5	Fl_D	

C_2H_4O Acetaldehyde

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.97–57.0	Fl_U Wide tube	(64)
	4.27–13.4	Fl_D	

C_2H_6O Ethyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.07–		(18)
Air..........	4.0 –		(21)
Air..........	3.95–13.7	E_{110}	(23)
Air..........	4.0 -13.7		(29)
Air..........	2.8 -9.5		(51)
Air..........	3.56–18.0	Fl_U Wide tube	(64)
	3.74–11.5	Fl_D	
Air..........	5.02–	Fl_U	
	5.18–	Fl_H $Tb_{2.5}$, 60°	(56)
	5.21–	Fl_D	
	4.24–19.0	Fl_U	
	4.32–13.8	Fl_H Tb_5, 60°	(56)
	4.44–11.5	Fl_D	
	4.16–	Fl_U	
	4.37–	Fl_H Tb_{15}, 60°	(56)
	4.23–	Fl_D	

C_3H_6O Acetone

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.9 –		(18)
Air..........	2.7 –		(21)
Air..........	5.0 -12.0		(29)
Air..........	2.15– 9.7	Fl_U	(52)
	2.35– 8.5	Fl_D	(52)
Air..........	2.3 – 7.5	Fl_U	
	2.4 – 6.7	Fl_H $Tb_{2.5}$	(56)
	2.75– 6.5	Fl_D	
	2.2 – 9.5	Fl_U	
	2.25– 9.3	Fl_H Tb_5	(56)
	2.40– 8.3	Fl_D	
	2.15– 9.7	Fl_U	
	2.20– 9.5	Fl_H Tb_{10}	(56)
	2.35– 8.5	Fl_D	
	2.88–12.4	Fl_U	
	2.89–12.4	Fl_H Tb_{15}	(56)
	3.11–10.9	Fl_D	
Air..........	2.89–13.0	Fl_U Wide tube	(64)
	2.93– 8.6	Fl_D	
Air..........	3.59– 9.6	Glass pipette	(73)
	4.03– 8.5	Glass bulb	(73)
	3.68– 8.6	(20°) Iron tube	(73)
	3.30–10.1	100°	

C_3H_6O Allyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.04		(18)

C_3H_8O *n*-Propyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.55–	E_{2000}	(18)

C_3H_8O Isopropyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.65–	E_{2000}	(18)

C_4H_8O Ethylmethyl Ketone

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.97–10.1	Fl_U Wide tube	(64)
	2.05– 7.6	Fl_D	

$C_4H_8O_2$ Ethyl Acetate

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.26–11.4	Fl_U Wide tube	(64)
	2.33– 7.1	Fl_D	

$C_4H_{10}O$ Ether

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.9 –		(18)
Air..........	1.8 – 5.2		(21)
Air..........	2.75– 7.7	E_{110}	(23)
	1.6 –	Fl_D, $Tb_{6.2}$	(23)
Air..........	0.59–0.195*		(25)
Air..........	2.7 – 7.7		(29)
Air..........	2.35–18.5	Fl_U	
	2.38– 6.2	Fl_H $Tb_{2.5}$	(56)
	2.34– 6.3	Fl_D	
	1.93–15.8	Fl_U	
	2.05– 8.0	Fl_H Tb_5, 20°	(56)
	2.15– 6.2	Fl_D	
	1.93–17.1	Fl_U	
	2.05–13.0	Fl_H Tb_5, 60°	(56)
	2.15– 7.5	Fl_D	
	1.73–23.3	Fl_U	
	1.93–22.3	Fl_H Tb_{15}	(56)
	1.80– 6.5	Fl_D	
	1.87–	P_{770}, Fl_H	(56)
	-12.9	P_{751}, Fl_H	(56)
	-10.5	P_{600}, Fl_H	(56)
	– 9.2	P_{520}, Fl_H	(56)
	1.88–	P_{460}, Fl_H	(56)
	– 8.2	P_{450}, Fl_H	(56)
	– 7.8	P_{400}, Fl_H	(56)
	1.92– 7.3	P_{300}, Fl_H	(56)
	2.08– 6.8	P_{200}, Fl_H	(56)
	2.33– 6.1	P_{100}, Fl_H	(56)
	2.99– 5.0	P_{50}, Fl_H	(56)
	– 6.2	P_{600}, Fl_D	(56)
	– 6.2	P_{300}, Fl_D	(56)
	– 5.9	P_{200}, Fl_D	(56)
	– 5.5	P_{100}, Fl_D	(56)
		P_{50}	(56)
Air..........	1.71–48.0	Fl_U Wide tube	(64)
	1.85– 6.4	Fl_D	
Air..........	2.26–6.90	Glass pipette	(73)
	2.38–6.51	Glass bulb	(73)
	2.34–6.15	(20°)	
	1.97–	100° Iron tube	(73)
	1.63–	200°	

* Gm per l.

$C_4H_{10}O$ Isobutyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.68–	E_{2000}	(18)

CS_2

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.94–		(18)
Air..........	4.1 –		(21)
Air..........	2.5 -45.0		(51)
Air..........	1.06–50.0	Fl_U Wide tube	(64)
	1.91–35.0	Fl_D	

CS_2.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.11–31.7	Glass pipette	(73)
	2.22–31.2	Glass bulb	(73)
	3.38–29.2	(20°) Iron tube	(73)
	1.35–33.1	100° Iron tube	

C_2N_2 Cyanogen

Atm.	Limits	Exper. condn.	Lit.
Air..........	7.6–38.0		(51)

C_5H_5N Pyridine

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.81–12.4	Fl_U Wide tube	(64)
	1.88– 7.2	Fl_D Wide tube	

$C_2H_5NO_3$ Ethyl Nitrate

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.01– 7.5	Fl_U Wide tube	(64)
	3.83–15.1	Fl_D Wide tube	

Water Gas (50% H_2, 50% CO)

Atm.	Limits	Exper. condn.	Lit.
Air..........	12.5–66.5		(19)
Air..........	12.4–66.8	E_{110}, Sat.	(23)
	12.3–	Fl_D, $Tb_{6.2}$	(23)

Water Gas (49.45% H_2, 47.90% CO, 2.65% air)

Atm.	Limits	Exper. condn.	Lit.
Air..........	12.4–66.2	E_{120}	(60)
O_2...........	12.6–92.1	E_{120}	(60)
$O_2:N_2$			
38.6:61.4....	12.5–81.3	E_{120}	(60)
52.7:47.3	12.6–86.1	E_{120}	

Mixtures of Combustible Gases (56)

$E_{15\,600}$, Fl_U

Vol. compn.	Limits
H_2 : CO : CH_4	
100	4.1 –71.5
75 : 25	4.7 –
50 : 50	6.05–71.8
25 : 75	8.2 –
10 : 90	10.8 –
100	12.5 –73.0
90 : 10	11.0 –
75 : 25	9.5 –
50 : 50	7.7 –22.8
40 : 60	7.2 –
25 : 75	6.4 –
100	5.6 –15.1
25 : 75	4.7 –
50 : 50	4.6 –
75 : 25	4.1 –
90 : 10	4.1 –
33 : 33 : 33	5.7–29.9
55 : 15 : 30	4.7 –
48.5 : 51.5	–33.6

Relative Limiting Igniting Pressures (89)

Below which, under the same sparking conditions, explosive mixtures would not ignite; P = limiting ignition pressure in mm Hg.

% H_2 in O_2	P	% CO in O_2	P
92.3	285	94.0	>400
91.7	341	93.9	75
88.9	212	92.5	108
85.7	183	91.0	99
80.0	149	88.9	81
75.0	123	85.7	78
66.7	103	80.0	55
50.0	66	75.0	50
40.0	53	66.7	50
36.7	53	50.0	30
33.3	45	40.0	26
25.0	52	37.5	24
16.7	54	35.3	27
11.8	57	33.3	32
9.1	72	25.0	74
8.8	68*	20.0	92
6.7	80*	18.4	106
		17.0	124
		16.0	135
		15.0	148
		14.3	340
		14.0*	
		13.8*	

* Incomplete combustion.

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(For a key to the periodicals see end of volume)

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(40) Biluchowski and Lahocinski, *136*, **1**: 1038; 14. *359*, **9**: 605; 14. (41) Burgess and Wheeler, *4*, **105**: 2591; 14. (42) Burgess and Wheeler, *4*, **105**: 2596; 14. (43) Le Prince Ringuet, *34*, **158**: 1793; 14. (44) Le Prince Ringuet, *34*, **158**: 1999; 14. (45) Reis, *7*, **88**: 518; 14. (46) Burrell and Oberfell, *30*, No. **112**; 15. (47) Burrell and Oberfell, *30*, No. **119**; 15. (48) Burrell and Boyd, *45*, **7**: 414; 15. (49) Burrell and Robertson, *45*, **7**: 417; 15.

(50) Burrell and Oberfell, *30*, No. **134**; 16. (51) Thornton, *3*, **33**: 190; 17. (52) Burrell and Ganger, *30*, No. **150**; 17. (53) Wheeler and Whitaker, *4*, **111**: 267; 17. (54) Payman, *54*, **37**: 406; 18. (55) Mason and Wheeler, *4*, **113**: 45; 18. (56) Coward, Carpenter and Payman, *4*, **115**: 27; 19. (57) White and Price, *4*, **115**: 1426; 19. (58) Payman, *4*, **115**: 1436; 19. (59) Satterly and Burton, *69*, **13**: 211; 19.

(60) Terres, *397*, **63**: 785, 805, 820, 836; 20. (61) Jorissen, *70*, **39**: 715; 20. (62) Chapman, *4*, **119**: 1677; 21. (63) Katz and Smith, *313*, No. **2400**: 11; 22. (64) White, *4*, **121**: 1244; 22. (65) White, *4*, **121**: 1688; 22. (66) White, *4*, **121**: 2561; 22. (67) Jorissen, *176*, **19**: 193; 22. (68) Boussu, *34*, **175**: 30; 22. (69) Asch, *97*, **4**: 468; 23.

(70) Builder, *136*, **47**: 435; 23. (71) Payman and Wheeler, *4*, **123**: 426; 23. (72) Jones, Yant and Berger, *45*, **16**: 353; 24. (73) Berl and Fischer, *9*, **30**: 29; 24. (74) White, *4*, **125**: 2387; 24. (75) Jorissen and Velisek, *70*, **43**: 80; 24. (76) Jorissen and Meuwissen, *70*, **43**: 591; 24. (77) White, *4*, **127**: 48; 25. (78) White, *4*, **127**: 672; 25. (79) Jorissen and Meuwissen, *70*, **44**: 132; 25.

(80) Crouch and Carver, *45*, **17**: 641; 25. (81) Jorissen and Valk, *70*, **44**: 810; 25. (82) Jorissen and Ongkiehong, *70*, **44**: 814; 25. (83) Jorissen, *70*, **44**: 1039; 25. (83a) Burgers and Wheeler, Safety in Mines Research Board, *Paper* No. **15**; 26. (83b) Coward and Hartwell, *Ibid.*, No. **19**; 26. (83c) Jorissen and Ongkiehong, *70*, **45**: 162, 224, 400; 26. (83d) Explosives in Mines Committee, *3rd Report*. London, H. M. Stationery Off., 1913.

LIMITING PRESSURES

([84]) Meyer and Seubert, *4*, **45**: 581; 84. ([85]) Dixon, *62*, **175**: 634; 84. ([86]) De Hemptinne, *186*, 761; 02. ([87]) Fischer and Wolf, *25*, **44**: 2956; 11. ([88]) Coward, Cooper and Warburton, *4*, **101**: 2278; 12. ([89]) Coward, Cooper and Jacobs, *4*, **105**: 1069; 14.
([90]) Stavenhagen and Schuchard, *92*, **33**: 286; 20. ([91]) Stavenhagen and Schuchard, *92*, **34**: 114; 21.

RELATIVE INFLAMMABILITIES

([92]) Emich, *57*, **18**: 6; 97. ([93]) Emich, *57*, **19**: 299; 98.

PROPAGATION OF FLAME

The "Uniform Movement" and Attendant Phenomena

Given certain conditions, an initial "slow uniform flame movement" can usually be effected in a gaseous explosive medium; its velocity is, however, dependent upon (1) the composition of the mixture, (2) its temperature and pressure, (3) the nature and dimensions of the containing vessel (in case of a tube, the diameter being the important dimension) and (4) the source and character of ignition. It is usually determined experimentally by igniting each explosive mixture with the same type of flame at the open end of a tube which is closed at the other end.

The flame movement so initiated usually proceeds at uniform velocity for a certain short distance, and its termination is marked by a period of accelerated vibrational flame movement, which may in some cases give rise to detonation. In other cases, however, it seems to be succeeded abruptly by detonation.

Recently attempts have been made to establish a so-called "law of flame speeds" for complex combustible gaseous mixtures, *e.g.*, coal-gas and air, on the supposition that in such cases the observed flame speed is caused by the oxygen or combustible gas (whichever of the two is in defect) dividing itself during the combustion so as to form a series of explosive mixtures (of each single component combustible gas with oxygen) giving the same flame speed. This, however, seems a fundamentally wrong view of things.

Abbreviations and Units

Tb_x. A tube of diameter x cm was used in experiment. The values given in the tables are the velocities of propagation of flame in cm/sec for the mixtures noted. All gas percentages are in volume %.

H_2

Tb_1 (4) H_2 in air		(8) $2H_2+O_2+4N_2$		Tb_1 (7) $2H_2+O_2+4N_2$		$Tb_{2.5}$ (27) H_2 in O_2	
% H_2	cm/sec	Tb_1	350	20°	350	% H_2	cm/sec
20	200	$Tb_{0.6}$	323	100°	430	59.9	574
25	280	$Tb_{0.3}$	350			66.6	662
30*	340	$Tb_{0.09}$	172			75.2	515
35	410	$3H_2 + Cl_2$					
40	440	Tb_1	315				
50	380	$H_2 + 3Cl_2$					
60	230	Tb_1	600				

* Not propagated in $Tb_{0.09}$ or less.

H_2 in air (16). A, in $Tb_{0.9}$; B, in $Tb_{1.15}$; C, in $Tb_{2.5}$

% H_2	A	% H_2	B	% H_2	C
11.80	No	17.30	150	6.10	No
17.30	125	25.15	260	6.19	10
23.65	200	33.90	383	6.31	12
30.45	320	37.15	400	20.15	260
36.55	390	40.10	410	29.70	405
40.10	420	43.10	420	36.30	490
43.10	420	46.80	400	40.50	480
46.80	400	51.55	360	44.55	460
50.55	353	57.15	270	49.15	385
57.00	280	59.45	175	61.60	145
62.00	155			71.39	50
63.50	No			71.51	*

* Flame to open end only.

CO

$Tb_{2.5}$ (23) CO in air, saturated with H_2O at room temp. and P = 1 atm.		Effect of H_2 and H_2O on flame speeds of CO–air mixtures (34)				
		t°	% CO	% H_2	% H_2O	cm/sec
		6	39.25	0.65	1.90	73.5
% CO	cm/sec	28	38.00	0.65	3.70	103.5
		4	39.70	1.90	0.80	103.5
16.15	*	6	46.15	3.85	0.90	152.0
16.29	19.5	10	47.30	4.05	1.20	150.0
16.51	19.4	29	46.00	4.05	3.95	167.0
24.47	34.0	20	47.30	4.15	2.30	144.0
30.50	46.0	5	37.45	5.60	0.85	170.0
44.84	60.1	6	43.75	5.60	0.90	170.5
59.58	56.2	31	42.20	5.60	44.0	156.0
67.10	30.2	6	40.80	6.05	0.90	160.5
70.63	20.0	27	39.60	6.05	3.50	158.0
71.19	19.4	Tb_1 (7)				
71.31	†	$2CO + O_2$, 220 cm/sec				

* Flame tongue.
† Flame to 15 cm.

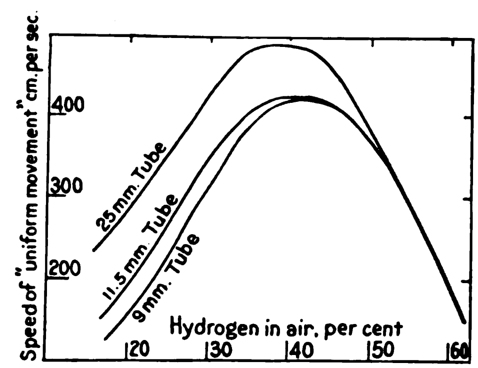

FIG. 5.—Influence of tube diameter on speed of "uniform movement" with mixtures of hydrogen and air (16).

Effect of H_2O on flame-speed (33). $Tb_{2.5}$. t° = temp. of saturation with H_2O

t°	% H_2O	cm/sec	t°	% H_2O	cm/sec	t°	% H_2O	cm/sec
2*	0.70	56	42*	8.00	118	27†	3.50	96
13*	1.45	76	4†	0.80	56	34†	5.20	107
27*	3.50	106	12†	1.35	68	39†	6.85	107
34*	5.20	120	20†	2.30	86			

* = 45 % CO in air.
† = 40 % CO in air.

CH_4 Methane

CH_4 in air (12); *cf.* (3, 6, 7, 8). A in glass $Tb_{2.65}$; B in lead $Tb_{2.64}$; C in copper $Tb_{2.3}$; D in iron $Tb_{2.72}$					CH_4 in air (13) Tb_5	
					% CH_4	cm/sec
% CH_4	A	B	C	D	5.4	36
5.99	21.7	19.4	18.3	21.2	6.8	55
6.83	33.4	32.5	32.7	34.1	8.8	100
7.6	45.6	43.5	42.4	43.8	9.45	110
7.95	48.6	48.2	45.2		10.6	109
8.94	63.66	58.7	59.4	63.3	11.5	84
10.0	69.8	65.0	63.2	67.3	13.0	42
10.98	61.1	53.9	54.1	57.5	14.3	36
11.3	53.3	45.4	47.7	50.6		
11.74	36.9	35.2	34.5	36.1		

"Uniform-movement" velocities in tubes of small diameter [20]. D = internal diam. of tube in mm; % = % CH_4 in air

D \ %	7.6	8.0	8.25	8.4	8.5	9.0	9.5	9.95	10.15
3.6	0	0	0	0	0	0	0	0	0
4.5	0	0	(20)	(18)	(20)	(20)	(20)	(33)	0
5.6	(25)	(20)	(27)		36.3	38.4	40.8	41.2	40.8
7.2	(37)	(30)	(30)	(30)	38.0	40.5	46.8	46.3	44.5
8.1	(45)	(30)	(35)	36.5	39.3	42.4	47.7	47.4	46.7
9.0	(55)	32.6	34.8		40.4	44.4	48.9	48.0	47.9

D \ %	10.5	10.65	10.8	11.0	11.5	11.6	11.65	12.0
3.6	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0
5.6	38.4	0	0	0	0	0	0	0
7.2	42.9	(60)	(53)	(43)	0	0	0	0
8.1	44.0	42.2	41.0	(45)	(50)			(60)
9.0	46.5	45.5		42.5	36.9	35.3	(69)	(60)

Figures in parentheses denote distance travelled before flame died out.

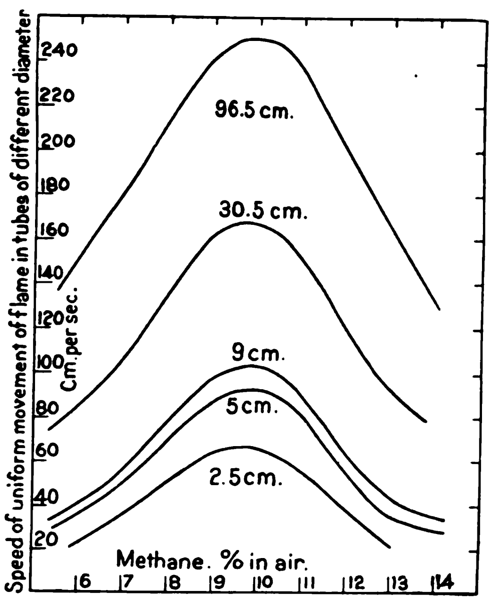

FIG. 6.—Influence of tube diameter on speed of "uniform movement" with mixtures of methane and air [19].

CH_4 in air, $Tb_{2.5}$ [23]		CH_4 in O_2 [27]	
% CH_4	cm/sec	% CH_4	cm/sec
5.71	*	5.59	†
5.80	23.3	5.72	20
6.95	35.0	10.52	266
7.82	47.4	15.53	722
9.12	64.4	21.63	2300
9.96	66.2	26.95	3991
10.32	65.5	33.00	5502
11.10	57.0	40.00	3020
12.25	35.0	45.61	488
13.09	22.0	53.36	82
13.35	19.1	57.67	29
13.42	†	59.50	‡

* Flame to 15 cm.
† Flame to 5 cm.
‡ Flame to 30 cm.

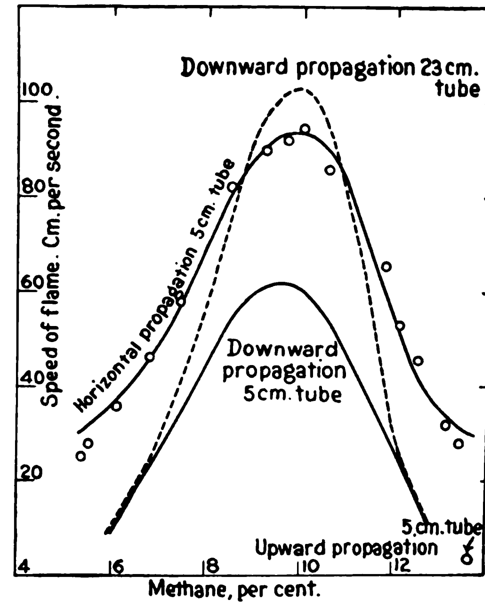

FIG. 7.—Influence of the direction of flame propagation on speed of "uniform movement" with mixtures of methane and air [28].

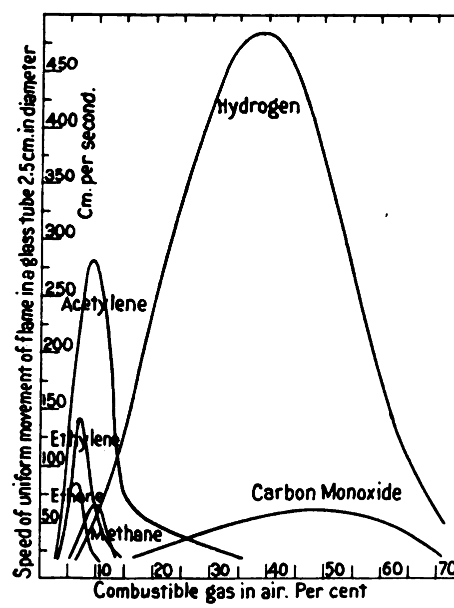

FIG. 8.—Comparison of the speeds of "uniform movement" of mixtures of various individual gases with air [29].

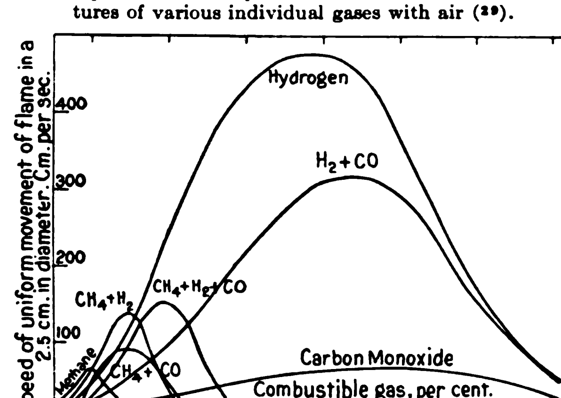

FIG. 9.—Speeds of "uniform movement" of mixtures of combustible gases with air [23].

C_2H_2 Acetylene

C_2H_2 in air		C_2H_2 in air		C_2H_2 in air (22)				
Tb_4 (9)		$Tb_{0.9}$ (17)		% C_2H_2	Diam. of tube in mm			
% C_2H_2	cm/sec	% C_2H_2	cm/sec		12.5	25	50	90
2.9*	10	4	45	2.75				40
8.0	500	6	147	3.45	25	41	60	
9.0–10.0	600	8	260	4.40				115
22.0	40	9	266	4.60	82	95	115	
64*	5	10	264	6.10	158	172	205	
		12	175	7.00				265
		14	114	8.15	258	270	303	
		16	75	9.45				335
		18	50	10.35	260	278	304	
		20	38	11.6	206	245	283	
				11.85				285
				13.25	115	145	175	220
				16.00	60	68	72	
				18.20			60	70

* Limit.

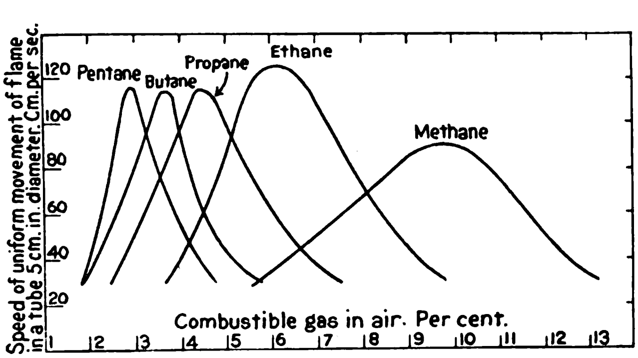

FIG. 10.—Speed of "uniform movement" of mixtures of the paraffin series with air (31).

C_2H_4 Ethylene		C_2H_6 Ethane		C_3H_8 Propane		C_4H_{10} Butane	
In air (29)		In air (23)		In air (23)		In air (22)	
$Tb_{2.5}$ % C_2H_4	cm/sec	$Tb_{2.5}$ % C_2H_6	cm/sec	$Tb_{2.5}$ % C_3H_8	cm/sec	$Tb_{2.5}$ % C_4H_{10}	cm/sec
3.55	25.8	3.16	*	2.30	‡	1.90	‡
4.00	41.3	3.30	18.1	2.37	20.8	1.95	20.1
6.10	108.4	3.58	25.6	2.58	26.0	2.05	23.3
6.50	129.9	4.47	52.7	2.80	31.4	2.57	49.1
7.20	142.4	4.90	65.0	3.50	48.2	3.01	67.9
8.10	120.6	5.57	80.5	4.28	72.8	3.40	80.2
9.45	72.6	6.08	82.5	4.39	79.1	3.66	82.6
13 35	23.5	6.53	85.6	4.71	82.1	4.05	75.0
14 00	22.2	7.07	81.3	4.84	80.2	4.34	61.9
		7.70	60.4	5.14	66.0	4.88	43.4
		8.23	45.8	5.90	41.2	5.50	27.7
		9.00	27.7	6.58	30.2	6.27	22.0
		9.50	23.1	7.10	23.0	6.53	20.3
		10.09	20.8	7.30	20.3	6.60	‖
		10.60	19.7	7.35	§		
		10.71	†				

* Flare only.
† Flame to 4 cm.
‡ Flame to 6 cm.
§ Flame to 15 cm.
‖ Flame to open end only.

C_5H_{12} Pentane				C_3H_6O Acetone		CS_2+3NO (7)	
In air (23). $Tb_{2.5}$				In air (17)		*Cf.* (5, 8)	
% C_5H_{12}	cm/sec	% C_5H_{12}	cm/sec	$Tb_{2.5}$			
1.52	*	3.85	48.0	% C_3H_6O	cm/sec		
1.61	20.2	4.00	44.0	2.70	55.0	Tb_3	125
1.98	40.1	4.32	33.0	3.85	69.0	Tb_2	124
2.35	60.2	4.56	28.7	5.05	93.8	Tb_1	75
2.63	74.3	4.87	25.8	6.40	68.5	$Tb_{0.4}$	
2.92	83.0	5.40	20.2	7.65	39.5		
3.00	82.1	5.50	†	8.20	30.5		
3.13	76.0						
3.35	65.9						
3.49	61.5						

* Flame to 6 cm. † Flame to open end only.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bunsen, *8*, **131**: 161; 67. (2) Mallard, *15*, **7**: 355; 75. (3) Fonseca Benevides, *407*, **7**: 166; 80. (4) Mallard and Le Chatelier, *34*, **93**: 145; 81. (5) Mallard and Le Chatelier, *34*, **95**: 599; 82. (6) Mallard, *185*, **15**: 268; 82. (7) Mallard and Le Chatelier, *51*, **1**: 173; 82. *27*, **39**: 369, 572; 83. (8) Mallard and Le Chatelier, *15*, **4**: 296; 83. (9) Le Chatelier, *34*, **121**: 1144; 95.

(10) Bunte, *25*, **31**: 19; 98. (11) Sellars and Campbell, *54*, **32**: 730; 13. (12) Parker and Rhead, *4*, **105**: 2150; 14. (13) Wheeler, *4*, **105**: 2606; 14. (14) Morgan, *115*, **99**: 39; 15. *67*, **26**: 172; 14. (15) Parker, *4*, **107**: 328; 15. (16) Haward and Otagawa, *4*, **109**: 83; 16. (17) Wheeler and Whitaker, *4*, **111**: 267; 17. (18) Haward and Sastry, *4*, **111**: 841; 17. (19) Mason and Wheeler, *4*, **111**: 1044; 17.

(20) Payman and Wheeler, *4*, **113**: 656; 18. (21) Payman and Wheeler, *4*, **115**: 36; 19. (22) Mason and Wheeler, *4*, **115**: 578; 19. (23) Payman, *4*, **115**: 1446, 1454; 19. (24) Morgan, *115*, **108**: 535; 19. (25) Nickolls, *Underwriters Labs. Special Investigation* No. 528; 19. (26) Mason and Wheeler, *4*, **117**: 36; 20. (27) Payman, *4*, **117**: 48; 20. (28) Mason and Wheeler, *4*, **117**: 1227; 20. (29) Chapman, *4*, **119**: 1677; 21.

(30) Payman and Wheeler, *4*, **121**: 363; 22. (31) Mason, *4*, **123**: 210; 23. (32) Payman, *4*, **123**: 412; 23. (33) Payman and Wheeler, *4*, **123**: 1251; 23. (34) Ellis, *4*, **123**: 1435; 23. (35) Campbell and Ellis, *4*, **125**: 1957; 24. (36) Ellis and Stubbs, *4*, **125**: 1960; 24. (37) Ellis and Robinson, *4*, **127**: 760; 25. (38) Ellis and Wheeler, *4*, **127**: 764; 25. (39) Gouy, *6*, **18**: 1; 79.

(40) Bunte, *25*, **31**: 19; 98. (41) Hofsass, *397*, **62**: 541; 19. (42) Payman and Wheeler, *83*, preprint, 1926.

THEORETICAL

(43) Vicaire, *6*, **19**: 118; 70. (44) Mallard and Le Chatelier, *15*, **4**: 296; 83. (45) Jouguet, *34*, **156**: 872; 13. (46) Nusselt, *98*, **59**: 872; 15. (47) Jouguet and Crussard, *34*, **168**: 820; 19.

DETONATION

The phenomenon of detonation, or "l'onde explosive" as it was originally known, in gaseous explosions was discovered by Berthelot and Vieille and by Mallard and Le Chatelier in the year 1881. It is set up when a sufficiently explosive mixture is ignited by means of a detonator (such as fulminate) or under circumstances such that the burning gases are exposed to the repeated effects of reflected compression waves. In the last named circumstance the initial uniform slow velocity is rapidly accelerated up to the point of detonation.

When once established its velocity is constant and within wide limits unaffected by the material and diameter of the tube employed, being solely dependent on the nature of the explosive mixture and on its temperature and pressure.

In the explosion wave the explosive mixture is fired adiabatically by compression so that the chemical reaction is more intense and of much shorter duration than in the case of normal combustion. In addition the pressure in the wave is much greater than in ordinary explosions, this being the cause of its shattering effect.

Abbreviations

Values not otherwise designated are detonation velocities in meters per second.

Composition of gas mixtures when given in percentages are in volume %.

The initial conditions of the detonating mixture are ordinary temperature and pressure unless otherwise stated.

H_2

Determinations in a lead pipe 100 m long × 6 mm diam. (8)
For $2H_2 + O_2$, normal conditions, 2821

At 10°				At 100°			
P_{mm}	m/sec	P_{mm}	m/sec	P_{mm}	m/sec	P_{mm}	m/sec
200	2627	760	2821	390	2697	1000	2828
300	2705	1100	2856	500	2738	1450	2842
500	2775	1500	2872	760	2790		

$2H_2 + O_2$	2821	$2H_2 + 8O_2$	1281	$2H_2 + O_2 + N_2$	2426
$2H_2 + 2O_2$	2328	$4H_2 + O_2$	3268	$2H_2 + O_2 + 3N_2$	2055
$2H_2 + 4O_2$	1927	$6H_2 + O_2$	3527	$2H_2 + O_2 + 5N_2$	1822
$2H_2 + 6O_2$	1707	$8H_2 + O_2$	3532	$2H_2 + 2O_2 + 2N_2$	2003

$H_2 + N_2O$, at $P_{mm} = 500$, 2094; $P_{mm} = 760$, 2307; $P_{mm} = 1000$, 2302

Determinations in a lead pipe 100 m long × 9 mm diam. (24)

% H_2	% O_2	m/sec	% H_2	% O_2	m/sec	% H_2	% O_2	m/sec
22.2	77.8	1600	50.0	50.0	2311	85.5	14.5	3527
25.0	75.0	1693	66.7	33.3	2817	88.9	11.1	3532
33.3	66.7	1917	80.0	20.0	3278			

% H_2	% O_2	% N_2	m/sec	% H_2	% O_2	% N_2	m/sec
25.0	50.0	25.0	1756	33.3	33.3	33.3	1990
33.3	44.4	22.3	1961	50.0	25.0	25.0	2388
50.0	33.3	16.7	2374	66.6	16.7	16.7	2767
66.6	22.2	11.2	2822	75.0	12.5	12.5	2846
75.0	16.7	8.3	3090	33.3	26.6	40.1	2016
80.0	13.3	6.7	3137	50.0	20.0	30.0	2383
				66.6	13.3	20.1	2655
				71.4	11.4	17.2	2671

In glass tubes (22)				(8)		$H_2 + Cl_2$ in dark, dry, 1795 wet, 1770 (6)
Tube diam. =	9	12.7	15			
$2H_2 + O_2$	2821		2828	$H_2 + Cl_2$	1729	
$2H_2 + 4O_2$	1927	1921		$2H_2 + Cl_2$	1849	
$2H_2 + O_2 + 3N_2$	2055		2089	$3H_2 + Cl_2$	1855	

Determinations in rubber tube 40 m long × 5 mm diam. (3)

$2H_2 + O_2$, normal conditions, 2810				%$(2H_2 + O_2)$		% H_2 in air	
P_{mm}	m/sec	P_{mm}	m/sec	In air		30	1439
560	2763	1260	2776	45	1439	26.7	1201
760	2800	1580	2744	40	1251	23.3	1205
$2H_2 + N_2O$		2284		35	1205	21.7	*
$2H_2 + N_2 + O_2$		2121		32.5	*		

* Detonation not propagated.

ClO_2

53.5% ClO_2, 46.5% O_2, 1065. 64.0% ClO_2, 36.0% O_2, 1126 (11)

CO

(3)			
$2CO + O_2$		$CO + N_2O$ 1106	$2CO + O_2$ (13). In CO mixtures the speed may be influenced by nature of igniting charge.
P_{mm}	m/sec	$2CO + O_2 + 2N_2$ (1000)	Fired by
570	1120	30% CO in air not detonated	0.10 g chlorate powder...............1280*
760	1089		0.05 g fulminate....1900†
834	1072		0.75 g fulminate....1210‡
1560	1132		

* Wave variable. ‡ Undulatory.
† Explosive.

$2CO + O_2$; influence of H_2O vapor (8); $t°$ = saturation temp.

$t°$	% H_2O	P_{mm}	m/sec	$t°$	% H_2O	P_{mm}	m/sec
	Well-dried		1264	35	5.6	760	1738
	Dry		1305	35	5.6	1100	1782
10	1.2		1676	45	9.5	400	1570
20	2.3	400	1576	45	9.5	760	1693
20	2.3	760	1703	45	9.5	1100	1742
20	2.3	1100	1737	55	15.6		1666
28	3.7		1713	65	24.9		1526
35	5.6	400	1616	75	38.4		1266

CH_4 Methane

(8)				In O_2 (24)		(3)	
$CH_4 + 2O_2$		$CH_4 + 2O_2$	2146	% CH_4		$CH_4 + 2O_2$	2287
P_{mm}	m/sec	$CH_4 + 4O_2$	1963	11.1	1678	$CH_4 + 2N_2 + 4O_2$	1858
500	2280	$CH_4 + 1\frac{1}{2}O_2 + \frac{1}{2}N_2$	2349	20.0	1980		
760	2322			25.0	2146	$CH_4 + 4N_2 + 2O_2$	1151
1000	2319	$CH_4 + 1\frac{1}{2}O_2 + 1\frac{1}{2}N_2$	2154	33.3	2337		
$CH_4 + 1\frac{1}{2}O_2$				40.0	2465	$CH_4 + 7.52\ N_2 + 2O_2$ gives no detonation.	
500	2418	$CH_4 + 1\frac{1}{2}O_2 + 2\frac{1}{2}N_2$	1880	50.0	2513		
760	2470			53.3	2388		
1000	2488						

C_2H_2 Acetylene

(13)				(8)	
$2C_2H_2 + O_2$	2160	$C_2H_2 + 6O_2$	1950	$C_2H_2 + 2\frac{1}{2}O_2$	2391
$1\frac{1}{2}C_2H_2 + O_2$	2510	$C_2H_2 + 10O_2$	1850	$C_2H_2 + 1\frac{1}{2}O_2$	2716
$C_2H_2 + O_2$	2920	$C_2H_2 + 2N_2O$	2580	$C_2H_2 + 1\frac{1}{2}O_2 + N_2$	2414
$C_2H_2 + 3O_2$	2220	$C_2H_2 + 6N_2O$	2400	$C_2H_2 + O_2$	2961 (16)
$C_2H_2 + 4O_2$	2190	$C_2H_2 + 2NO$	2850	$C_2H_2 + 2\frac{1}{2}O_2$	2482 (3)
		$C_2H_2 + 6NO$	2800		

98% C_2H_2 (12). Determinations made in tube 1 m long × 3.5 mm diam. Since C_2H_2 is an endothermic compound, it can be detonated under pressure.

P = initial detonating pressure in kg/cm².

P.................	5	10	12	15	20	30
Speed..............	1050	1100	1280	1320	1500	1600

C_2H_4 Ethylene (8)

$C_2H_4 + 2O_2$*	2581	$C_2H_4 + 6O_2$	2118	$C_2H_4 + 2O_2 + 2N_2$	2211
$C_2H_4 + 2O_2$†	2538	$C_2H_4 + 8O_2$	1980		
$C_2H_4 + 3O_2$	2364	$C_2H_4 + 10O_2$	1856	$C_2H_4 + 2O_2 + 4N_2$	2024
$C_2H_4 + 4O_2$	2247	$C_2H_4 + 2O_2 + N_2$	2413		
(3)				$C_2H_4 + 2O_2 + 6N_2$	1878
$C_2H_4 + 3O_2$	2209				
				$C_2H_4 + 2O_2 + 8N_2$	1734

* 10°.
† 100°.

C_2H_6 Ethane

$C_2H_6 + 3\frac{1}{2}O_2$, 2363 (3)

C_2N_2 Cyanogen

(3)		(8)			(22)	
$C_2N_2 + 4N_2O$	2035	P_{mm}	$C_2N_2 + O_2$	$C_2N_2 + 2O_2$, 2321	$C_2N_2 + O_2 + 2N_2$	
$C_2N_2 + 2O_2$	2043	500	2536	$C_2N_2 + 3O_2$, 2110	Diam. of tube	m/sec
$C_2N_2 + 2N_2 + 2O_2$	1203	760	2677	$C_2N_2 + O_2 + N_2$, 2398	6 mm	2161
$C_2N_2 + 4N_2 + 2O_2$	*	1000	2671	$C_2N_2 + O_2 + N_2$, 2165	9 mm	2230
P_{mm}	$C_2N_2 + 2O_2$	$t°$			12.7 mm	2230
388	2171	10	2728			
758	2195	100	2711			
878	2052					

* Detonation not propagated.

Mixtures of Combustible Gases

(23)

$2(xH_2 + yCO) + O_2$			$4(xH_2 + yCO) + O_2$		
x	y	m/sec	x	y	m/sec
0.75	99.25	1754	1	99	1747
1.5	98.5	1758	2	98	1755
7.5	92.5	1796	5	95	1776
15	85	1858	25	75	1952
37.5	62.5	2020	50	50	2212
50	50	2130	75	25	2614
75	25	2391	85	15	2819
85	15	2507	92.5	7.5	3015
92.5	7.5	2643	100	0	3284
100	0	2810			

Mixture	m/sec	Lit.
$2H_2 + O_2 + 2CO$	2455	(8)
$2H_2 + O_2 + 6CO$	2080	(8)
$H_2 + O_2 + 2CO$	2143	(8)
$H_2 + O_2 + CO$	2008	(3)
$3H_2 + 2\frac{1}{2}O_2 + 2CO$	2170	(3)
$H_2 + C_2H_4 + 3\frac{1}{2}O_2$	2417	(3)
$2H_2 + C_2H_4 + 4O_2$	2579	(3)
$H_2 + C_2H_6 + 4O_2$	2250	(3)

$H_2 + CH_4$ (24). M = % mixture in O_2

$H_2 + CH_4$		$2H_2 + CH_4$		$H_2 + 2CH_4$	
M	m/sec	M	m/sec	M	m/sec
13.8	1532	14.3	1449	14.3	1728
21.0	1875	15.8	1582	25.0	2050
44.4	2464	16.7	1666	40.0	2444
50.0	2561	20.0	1764	46.1	2546
57.1	2697	33.3	2094	50.0	2605
66.7	2604	50.0	2474	54.5	2679
		54.5	2572	60.0	2600
		66.7	2782		

Limiting Dilutions of Explosive Mixtures for the Initiation of Detonation

Detonation cannot be propagated in mixtures diluted beyond the limits given

	Limits	Speed	Lit.
H_2 and air	Lower 23.3% H_2	1205	(3)
	Between 21.7% H_2	*	(3)
CO	$4CO + 2N_2 + O_2$	*	(3)
	$2CO + N_2 + O_2$	*	(3)
CH_4 Methane	$CH_4 + O_2$		
	Lower 11.1% CH_4	1678	(24)
	Upper 53.3% CH_4	2388	(24)
	$CH_4 + 4N_2 + 2O_2$	1151	(3)
	$CH_4 + 7.5N_2 + 2O_2$	*	(3)
	9.5% CH_4 in air	*	(3)
C_2H_2 Acetylene	$C_2H_2 + 10O_2$	1850	(13)
	$C_2H_2 + 6NO$	2800	(13)
C_2N_2 Cyanogen	$C_2N_2 + 2N_2 + 2O_2$	1203	(3)
	$C_2N_2 + 4N_2 + 2O_2$	*	(3)
	$C_2N_2 + 4N_2O$	2035†	(3)
	$C_2N_2 + 4NO$	*	(3)

* Detonation not propagated.
† Sometimes propagated.

Mean flame velocity before a uniform detonation speed ensues (3). $2H_2 + O_2$, in rubber tube 5 mm diam.; D = distance from initiating explosive in m; S = time in sec; V = mean vel. from origin in m/sec; $V_{\text{int.}}$ = mean vel. in each interval.

D	S	V	$V_{\text{int.}}$
0.020	0.000275	72.72	72.7
0.050	0.000342	146.2	448.0
0.500	0.000541	924.4	2261
5.250	0.002108	2491.0	3031
20.190	0.007620	2649.0	2710
40.430	0.015100	2679.0	2706

Distance in inches from spark at which detonation occurs = D_0 for spark at end of tube and D_3 for spark 3 in. from end (16).

Mixture	D_0	D_3
$2H_2 + O_2$	48	12
$2H_2 + 2\frac{1}{2}O_2$		48
$6H_2 + O_2$		192
$C_2N_2 + O_2$	$8\frac{1}{2}$	4
$C_2N_2 + 2O_2$	12	10
$2C_2H_2 + 3O_2$	$4\frac{1}{2}$	$2\frac{1}{2}$
$C_2H_4 + 2O_2$	9	5

Distance before detonation wave is established = D cm (13). Glass tube, 10 mm diam. Spark at end of tube

Mixture	D
$2C_2H_2 + O_2$	100
$C_2H_2 + O_2$	5
$C_2H_2 + 6O_2$	15
$C_2H_2 + 10O_2$	80
$C_2H_2 + 2NO$	20
$C_2H_2 + 6NO$	50
$C_2H_2 + 2N_2O$	100
$C_2H_2 + 6N_2O$	10

Influence of tube diameter on the distance from the firing source at which detonation occurs (25). Mixture = $CS_2 + 3O_2$. Spark at end of tube. D_{cm} = cm travelled by flame before detonation.

Tube diam., mm	D_{cm}
6.5–7	48
10	50
24–25	58
34–35	84
43–44	103
53–54	131

Distance required for the re-establishment of detonation waves after they are damped out by passing from one tube to another of larger diameter (26). Diam. of first tube = 7 mm. Distance in cm travelled by flame in second tube prior to detonation = D.

Diam. mm second tube	13	16	23–24	33–34	44–45
D ($CS_2 + 3O_2$)	8	10	15	50	100
D ($2H_2 + O_2$)			3	62	

Wave Velocities (14)

	$C_2H_2 + O_2$	$C_2H_2 + 2NO$	$2CO + O_2$
L'onde explosive (détonation wave)	2990	2850	1900
L'onde rétrograde (retonation wave)*	2300	1140	
L'onde réfléchie (reflexion wave)†	2250	1350	1000
L'onde prolongée (collision wave)‡	2050		

* A "retonation" wave is thrown back into the burnt gases when the detonation wave is set up.
† The wave reflected through the burnt gases after a detonation wave has reached the walls of the vessel in which the explosion occurs.
‡ Collision waves occur when two detonation waves meet.

Reflected Waves in a $C_2H_2 + O_2$ Mixture

Initial speed	2300	After first crossing	1080
After reflection	1350	After second crossing	980

Ratio of Wave Velocities ([16])

Mixture	Detonation wave velocity	Reflection wave velocity	Ratio of velocities
$2H_2 + O_2$	2820	1538	1.83
$H_2 + N_2O$	2305	1383	1.67
$2CO + O_2$	1676	1078	1.56
$C_2N_2 + O_2$	2728	1230	2.22
$C_2N_2 + 2O_2$	2321	1129	2.06
$2C_2N_2 + 5O_2$	2391	1133	2.11

Two equations of importance have been deduced whereby velocities of detonation agreeing closely with experimental values may be calculated ([34, 35]).

$$V^2 = \frac{2RJ}{\mu C_v^2}[\{(m-n)C_p + mC_v\}C_pT_o + (C_p + C_v)h] \text{ where}$$

V	Velocity of wave.
R	Gas constant.
J	Dynamical equivalent of heat (42×10^6 ergs).
μ	Gram equivalents of the mixture exploded.
n and m	Number of molecules before and after the chemical change in the wave.
C_p and C_v	Mean specific heats of the products at constant pressure and volume, respectively.
h	Total heat generated in the wave.
T_o	Initial temperature (abs.) of the mixture exploded.

$$\left(\frac{dP}{dt}\right)^2 = \mu^2 \frac{Rk_2T_2}{M}\left(1 + \frac{k_2R}{MC_2}\right), \text{ where}$$

$\left(\frac{dP}{dt}\right)$	Velocity of the wave.
R	Gas constant.
M	Molecular mass of the gas taken.
T_2	Temperature of the flame.
μ	$\frac{d_2}{d_1}$ (ratio of the final and initial densities).
C_2	Mean specific heat at constant volume of the explosion products.
k_2	Number of molecules in the explosion products.

LITERATURE

(For a key to the periodicals see end of volume)

Experimental

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Theoretical

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EXPLOSIONS IN CLOSED VESSELS

Much of the experimental determination of explosion times and pressures using gaseous mixtures has been carried out with coal gas—air mixtures. Owing to the variable composition and heat of combustion of the samples of coal gas so employed, it has not been found possible to tabulate such data except in so far as they may have a general bearing on the subject of gaseous explosions—and more particularly where data relative to the simpler combustible gases are lacking.

All maximum pressures have been expressed as a ratio, $\frac{\text{maximum pressure}}{\text{initial pressure}}$, thus giving a better basis of comparison. In most cases the published figures for initial pressures refer to room temperatures. Where this has been found to be otherwise, the initial pressures have been adjusted to correspond to a temperature of 15°C, and a corresponding correction applied to maximum pressures.

No attempt has been made to tabulate investigators' estimates of their explosion temperatures because (*a*) an arbitrary correction must necessarily be applied for cooling loss during the explosion period—this being dependent on the explosion vessel employed and (*b*) allowances must be made for dissociation. An approximate value of the temperature attained may be calculated from the formula

$$T_{(\text{max.})\,\text{abs.}} = \frac{P_{\text{max.}}}{P_{\text{init.}}} \times T_{(\text{init.})\,\text{abs.}} \times \frac{m}{n}$$

where m/n represents the molecular change.

Few direct determinations of explosion temperatures have been possible owing to the very high temperatures developed.

In comparing explosion times, consideration must be given to the dimensions of the explosion vessels concerned—on which they are solely dependent.

In the following tables all results may be considered to refer to explosions of gaseous mixtures at atmospheric pressure and temperature unless specially stated otherwise.

Abbreviations

$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Ratio of maximum pressure developed to initial pressure.
$P_{\text{init.}}$	Initial pressure in atmospheres.
$T_{\text{init.}}$	Initial temperature in °C.
V_x	Vessel whose capacity is x cm^3, unless otherwise stated.
Cyl.	Cylindrical.
Con.	Conical.
Sphere	Spherical.
Exper. condn.	Experimental conditions.
Milli-sec	Time in milli-seconds to attain maximum pressure.

H_2

Mixture	$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
$2H_2$				
$+O_2$	9.5		Cyl., V_{18}	([2])
$+O_2 + 4N_2$	6.5	10	Cyl., V^*	([6])
$+O_2$	9.25		Cyl., V_{4000}	([9])
$+O_2 + 2H_2$	8.34		Cyl., V_{4000}	([9])
$+O_2 + 4H_2$	7.58		Cyl., V_{4000}	([9])
$+O_2 + 6H_2$	6.67		Cyl., V_{4000}	([9])
$+O_2 + 2O_2$	8.2		Cyl., V_{4000}	([9])
$+O_2 + 6O_2$	6.4		Cyl., V_{4000}	([9])
$+O_2 + N_2$	8.65		Cyl., V_{4000}	([9])
$+O_2 + 2N_2$	8.26		Cyl., V_{4000}	([9])
$+O_2 + 4N_2$	7.5		Cyl., V_{4000}	([9])
$+O_2 + 6N_2$	6.5		Cyl., V_{4000}	([9])

H_2.—(*Continued*)

Mixture	$P_{max.}$/$P_{init.}$	Millisec	Exper. condn.	Lit.
$+2N_2O$	12.85		Cyl., V_{4000}	(9)
$+2N_2O + 2N_2$	10.47			
$+O_2$	7.41	1.04	Cyl., V_{300}	(11, 15)
$+O_2$	9.69	2.14	Cyl., V_{4000}	(11, 15)
$+O_2 + \frac{1}{20} H_2$		2.27		
$+O_2 + \frac{1}{10} H_2$		2.53	Cyl., V_{4000}	(11, 15)
$+O_2 + \frac{1}{2} H_2$		2.41		
$+O_2 + H_2$		2.82		
$+O_2 + 2H_2$		1.67	Cyl., V_{300}	(11, 15)
$+O_2 + 2H_2$		4.22		
$+O_2 + 3H_2$		5.95		
$+O_2 + 4H_2$		9.67		
$+O_2 + 2O_2$		8.16		
$+O_2 + 6O_2$		16.04	Cyl., V_{4000}	(11, 15)
$+O_2 + N_2$		2.86		
$+O_2 + \frac{1}{2}N_2$		3.55		
$+O_2 + 2N_2$	8.63	6.87		
$+O_2 + 2N_2$	7.60	2.67	Cyl., V_{300}	(11, 15)
$+O_2 + 4N_2$	7.55	11.98	Cyl., V_{4000}	(11, 15)
$+O_2 + 4N_2$	7.34		Cyl., V_{300}	(11, 15)
$+O_2 + 6N_2$	6.64	24.45	Cyl., V_{4000}	(11, 15)
$+O_2 + 6N_2$	6.12		Cyl., V_{300}	(11, 15)
$+O_2 + 8N_2$		36.35	Cyl., V_{300}	(11, 15)
$+O_2$	8.48			
$+O_2 + \frac{1}{2}O_2$	8.37			
$+O_2 + 3O_2$	7.94		Cyl., V_{4000}	(13). cf. (5, 7)
$+O_2 + 6O_2$	7.0			
$+O_2 + 3H_2$	8.02			
$+O_2 + 4N_2$	6.8	9.5	Con., V_{115} in.³, ignit. at vertex	(68)
$+O_2 + 4N_2$	7.54†	8.4	1.15 Pinit. atm. Cyl., V*	(75)
$+O_2 + 4N_2$	7.96†	6.9	3.0 Tinit.	
$+O_2 + 4N_2$	8.14†	6.1	5.5 = 54°C	
$+O_2 + 4N_2$	7.98	5.5		
$+O_2 + 2N_2$	8.28	2.2		
$+O_2 + 4H_2$	8.1	1.0		
$+O_2 + 2H_2$	9.13	1.0	Tinit. = 15°C	
$+O_2$	9.3	0.7	Pinit. = 2 atm.	(75)
$+O_2 + 4O_2$	7.7	2.9	Cyl., V*	
$+O_2 + 2O_2$	8.8	1.5		
$+O_2 + 4CO_2$	5.65	25.5		
$+O_2 + 2CO_2$	7.10	4.6		
	7.7	5 or	3	
	7.8	less,	10	
	8.0	de-	25	
	8.1	creas-	50 Sphere,	
$+O_2 + 4N_2$	8.33	ing	75 Pinit. V_{240}	(79)
	8.50	at	100 Tinit. = 17°C	
	8.64	high-	125	
	8.67	er	150	
	8.80	Pinit.	175	
	7.7			
	7.84			
	8.05	Same as above except Pmax./ Pinit. has been corrected: Pmax. for cooling losses during combustion period; Pinit. for deviation from Boyle's law.		
	8.16			
$+O_2 + 4N_2$	8.43			(79)
	8.63			
	8.79			
	8.82			
	8.98			
H_2				
$+N_2O$		2.06	Cyl., V_{300}	(11, 15)
$+Cl_2 + 3.6H_2$	6.88		Cyl., V_{4000}	(13) cf. (5, 7)
% H_2 in air	Values calculated from published temp. estimates			
25.4	7.23		Cyl., V 30 cm	
15.3	5.03		diam., 30 cm deep	(61)
10.0	4.03			

CO

Mixture	$P_{max.}$/$P_{init.}$	Millisec	Exper. condn.	Lit.
2CO				
$+O_2$	10.1		Cyl., V_{18}	(2)
$+O_2 + 4N_2$	7.3		Cyl., V_{18}	(2)

* Diam. 7 in., depth 8 in.
† Calculated to Tinit. = 15°.

CO.—(*Continued*)

Mixture	$P_{max.}$/$P_{init.}$	Millisec	Exper. condn.	Lit.
$+O_2$	9.56			
$+O_2 + N_2$	8.82		Cyl., V_{4000}	(9)
$+O_2 + 2N_2$	8.28			
$+O_2 + 5N_2$	6.66			
$+O_2$	9.42			
$+O_2 + 1\frac{1}{2}CO_2$	7.50			
$+O_2 + 3CO_2$	6.50			
$+O_2 + 4\frac{1}{2}CO_2$	4.8			
$+O_2 + 1\frac{1}{2}CO$	8.33		Cyl., V_{4000}	(13) cf. (5, 7)
$+O_2 + 6CO$	7.01			
$+O_2 + 1\frac{1}{2}O_2$	8.52			
$+O_2 + 6O_2$	6.40			
$+O_2 + 3\frac{3}{4}N_2$	7.24			
$+O_2 + 7\frac{1}{2}N_2$	5.98			
$+O_2$	9.29	12.86	Cyl., V_{300}	(11, 15)
$+O_2$	9.93	15.51	Cyl., V_{4000}	(11, 15)
$+O_2 + N_2$		17.78	Cyl., V_{300}	(11, 15)
$+O_2 + 2N_2$		26.49	Cyl., V_{300}	(11, 15)
$+O_2 + CO_2$		27.18	Cyl., V_{300}	(11, 15)
$+O_2 + 2CO_2$		35.80	Cyl., V_{300}	(11, 15)
$+O_2$	10.0	12.5	4.3 Sphere, V_{240}	
$+O_2$	11.5	5.0	21.4 Pinit.	(73)
$+O_2$	12.1	5.0	50.0 Tinit. = 17°C.	
$+O_2 + 2A$	10.6	10	Sphere, V_{240}	
$+O_2 + 2O_2$	10.3	5	Pinit. = 35.7	(69)
$+O_2 + 2CO$	10.01	5	Tinit. = 17°C	
$+O_2 + 2N_2$	9.55	40		
$+O_2 + 4A$	10.20	25	Sphere, V_{240}	
$+O_2 + 4O_2$	9.20	5	Pinit. = 50	(69)
$+O_2 + 4CO$	9.00	10	Tinit. = 17°C	
$+O_2 + 4N_2$	8.30	190		
$+O_2 + 6A$	9.7	140	Sphere. V_{240}	
$+O_2 + 6CO$	7.9	130	Pinit. = 64.3	(69)
$+O_2 + 6N_2$	6.4	1100	Tinit. = 17°C	
	8.5	35	3.0	
	8.9	50	10.0	
	10.2	25	50.0 Sphere, V_{240}	
$+O_2 + 4A$	10.53	15	75.0 Pinit.	(79)
	10.63	10	100.0 Tinit. = 17°C	
	11.2	10	125.0	
	11.66	10	150.0	
	8.65	Same as above except Pmax./Pinit. has been corrected: Pmax. for cooling loss during combustion period; Pinit. for deviation from Boyle's law.		
	9.1			
	10.1			
$+O_2 + 4A$	10.3			(79)
	10.33			
	10.84			
	11.4			
	7.6	60	3.0	
	7.7	45	10.0 Sphere, V_{240}	
$+O_2 + 4O_2$	8.6	10	25.0 Pinit.	(73)
	9.2	5	50.0 Tinit. = 17°C	
	10.1	5	75.0	
	9.6	10	75.0 Sphere, V_{240}	
	9.8	5	100.0 Pinit.	
$+O_2 + 4CO$	10.0	5	125.0 Tinit. = 17°C	(79)
	10.13	5	150.0	
	9.48	Same as above except Pmax./Pinit. corrected for combustion period loss and deviation from Boyle's law.		(79)
	9.68			
$+O_2 + 4CO$	9.95			
	10.16			
	7.13	70	3.0	
	7.5	100	10.0	
	7.72	150	25.0	
	8.20	190	50.0 Sphere, V_{240}	
$+O_2 + 4N_2$	8.47	320	75.0 Pinit.	(79)
	8.80	400	100.0 Tinit. = 17°C	
	8.88	470	125.0	
	9.03	530	150.0	
	9.23	560	175.0	
	7.80	Same as above except Pmax./ Pinit. corrected for combustion loss and deviation from Boyle's law.		
	8.00			
	8.30			
	8.65			
$+O_2 + 4N_2$	9.14			(79)
	9.37			
	9.45			
	9.76			
	10.17			

Continued on p. 190.

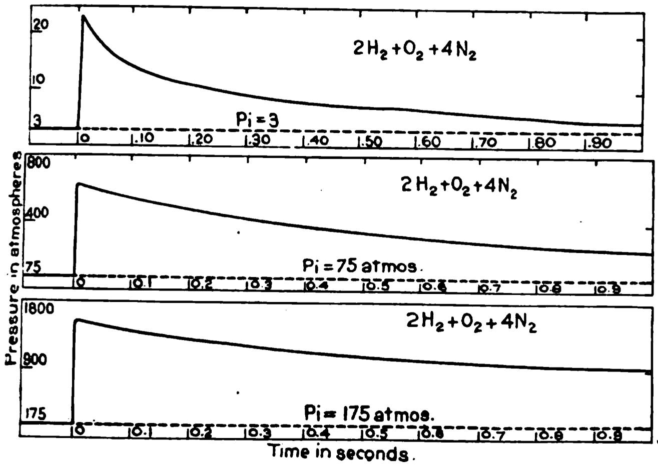

FIG. 11.—Time-pressure curves of $2H_2 + O_2 + 4N_2$ explosions at initial pressures of 3, 75 and 175 atm. [73, 79]. Spherical vessel, 2400 cc capacity.

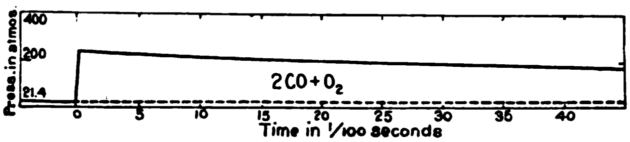

FIG. 12.—Time-pressure curve of $2CO + O_2$ explosion at an initial pressure of 21.4 atm. [69]. Spherical vessel, 240 cc capacity.

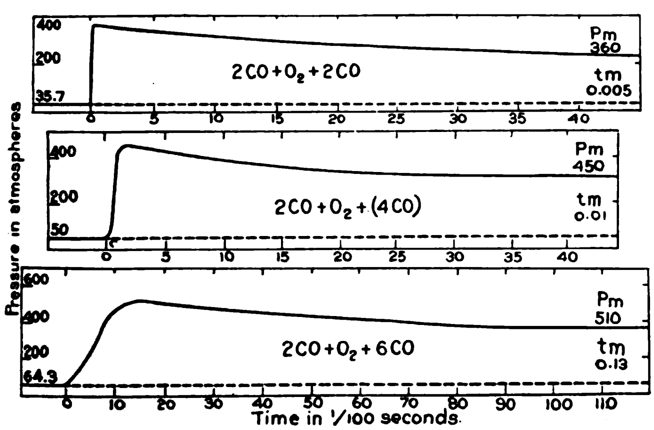

FIG. 13.—Time-pressure curves of $2CO + O_2 +$ (2CO, 4CO, 6CO) explosions at initial pressures of 35.7, 50 and 64.3 atm. respt. [69].

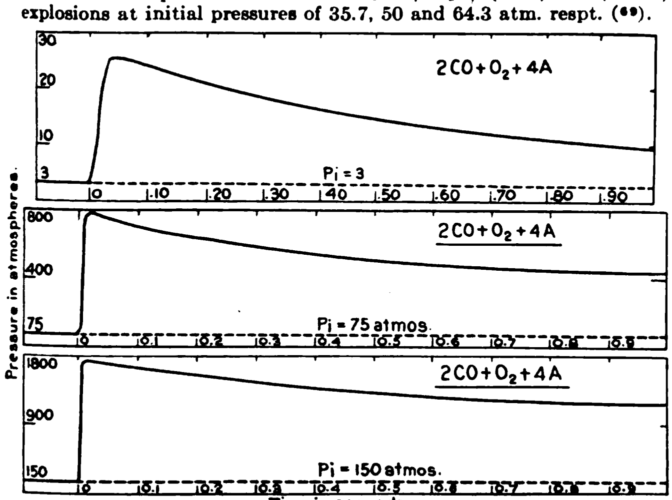

FIG. 15.—Time pressure curves of $2CO + O_2 + 4A$ explosions at initial pressures of 3.75 [73] and 175 atm. [79]. Spherical vessel, 240 cc capacity.

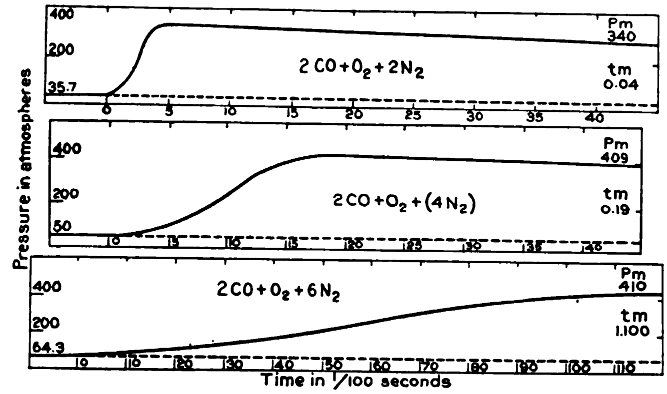

FIG. 14.—Time-pressure curves of $2CO + O_2 + (2N_2, 4N_2, 6N_2)$ explosions at initial pressures of 35.7, 50, and 64.3 atm. respt. [69].

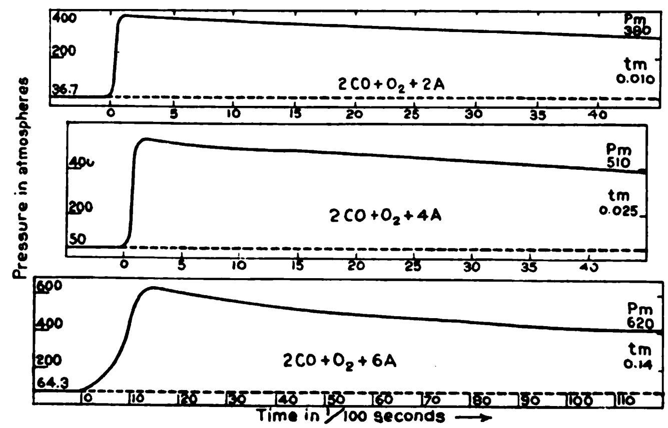

FIG. 16.—Time-pressure curves of $2CO + O_2 +$ (2A, 4A, 6A) explosions at initial pressures of 35.7, 50 and 64.3 atm. [69].

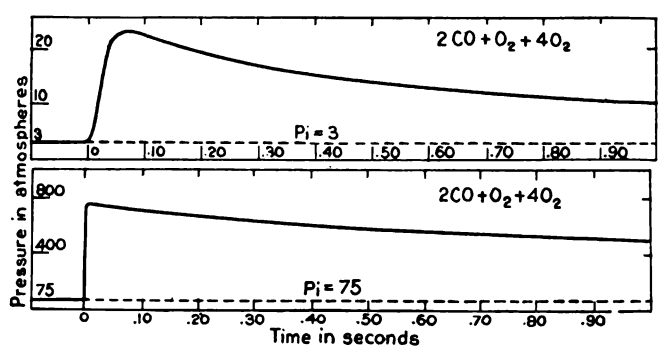

FIG. 17.—Time-temperature curves of $2CO + O_2 + 4O_2$ explosions at initial pressures of 3 and 75 atm. [73]. Spherical vessel, 240 cc capacity.

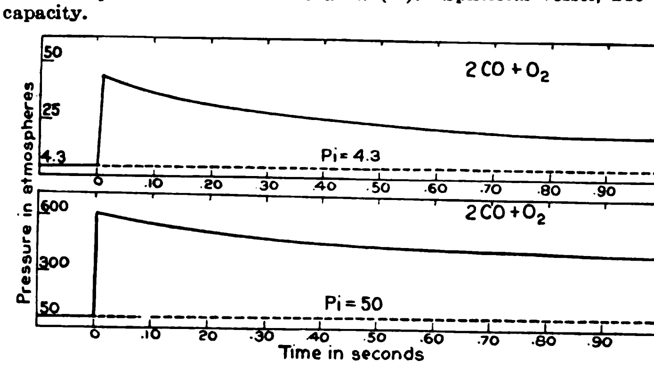

FIG. 18.—Time-pressure curves of $2CO + O_2$ explosions at initial pressures of 4 and 50 atm. [73]. Spherical vessel, 240 cc capacity.

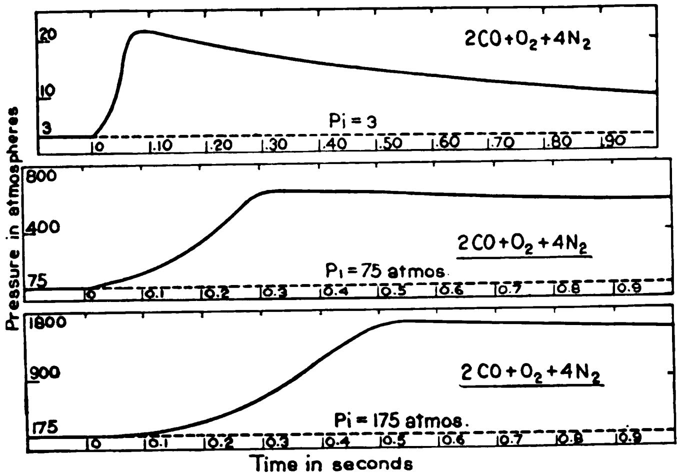

FIG. 19.—Time-pressure curves of $2CO + O_2 + 4N_2$ explosions at initial pressures of 3 ([79]), 75 and 175 atm. ([73]). Spherical vessel, 240 cc capacity.

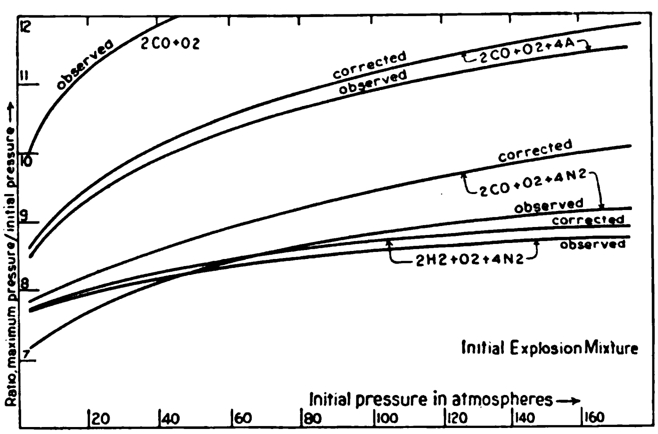

FIG. 20.—Influence of initial pressure on the ratio maximum pressure/initial pressure ([79]). Spherical bomb, capacity 240 cc. The corrected curve gives maximum pressure (corrected for cooling loss during combustion period)/initial pressure (corrected for deviation from Boyle's law).

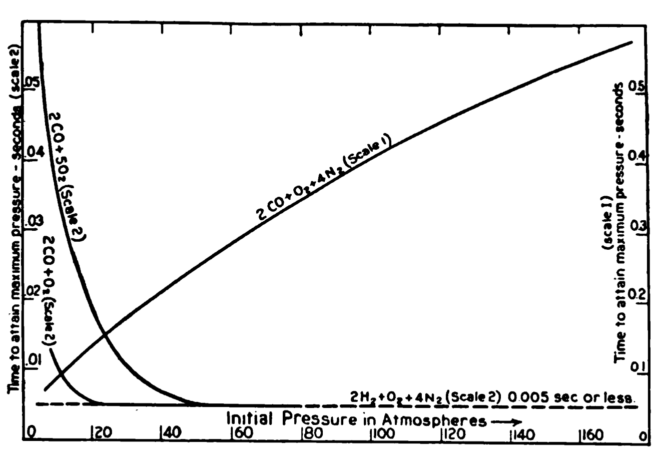

FIG. 21.—Influence of initial pressure on the time taken for the attainment of maximum pressure ([79]). Spherical bomb. capacity 240 cc.

CO.—(*Continued*)

Mixture	$P_{max.}/P_{init.}$	Milli-sec	Exper. condn.	Lit.
CO				
$+N_2O$	10.78		Cyl., V_{4000}	([9])
$+N_2O$		15.40	V_{300}	([11, 15])
% CO (97.5 %) in air				
20	5.77	800		
25	7.12	385	$P_{init.}$ = 2	
30	7.86	231	Sphere V, 16 in. diam.;	
35	8.16	211	silver plated interior;	
40	8.27	175	central ignition; gas	([76])
45	8.25	170	saturated with water	
50	7.65	189	vapor at room tem-	
55	7.10	251	perature	
60	6.05	390		
65	4.87	920		
	6.39	280	1	
	7.12	385	2	
	7.10	482	3	
25	7.22	550	4 $P_{init.}$	([76])
	7.39	668	5	
	7.24	990	6	
	7.47	1010	7	
	7.86	231	2	
30	8.25	335	4 $P_{init.}$	([76])
	8.85	560	6	

Influence of the amount of water vapor present. 29.3 % CO in air

Vol. H_2O vapor + 100 of mixture				
0	7.72*	290.2		
2.56	7.93*	90.1		
1.68	7.94*	97.0	Cyl. V, 7 in. diam.,	
1.67	7.94*	92.0	8 in. deep	([83])
1.24	7.96*	101.5	$T_{init.}$ = 50°C	
1.21	7.96*	101.0	$P_{init.}$ = 5	
0.60	7.94*	125.9		
0.30	7.89*	166.3		

* Calcd. to $T_{init.}$ = 15°.

Mixtures of H_2 and CO

2CO				
$+H_2 + 1\frac{1}{2}O_2$	9.28			
$+H_2 + 4O_2$	8.3		Cyl., V_{4000}	([9, 15])
$+3H_2 + 1\frac{1}{2}O_2$	8.92			
$+4H_2 + 3O_2$	9.08			
$2H_2 + O_2$		1.04	Cyl., V_{300}	([11])
$2CO + O_2$		12.86	Cyl., V_{300}	([11])
$2H_2$				
$+CO + 1\frac{1}{2}O_2$		2.57	Cyl., V_{300}	([11])
$+CO + O_2$		1.39	Cyl., V_{300}	([11])
H_2				
$+CO + O_2$		3.88	Cyl., V_{300}	([11])
$+2CO + 1\frac{1}{2}O_2$		4.14	Cyl., V_{300}	([11])
$2(xH_2 + yCO) + O_2 + 4N_2$				
x y				
100 0	8.10*	7.5		
49.7 50.3	8.10*	15.5	Cyl. V, 7 in. diam.,	
24.8 75.2	8.10*	29.3	8 in. deep	
11.9 88.1	8.10*	46.5	$P_{init.}$ = 5	([83])
8.0 92.0	8.10*	56.6	$T_{init.}$ = 50°C	
4.1 95.9	8.05*	75.9		
0.2 99.8	7.79*	245.9		
$2(xH_2 + yCO) + O_2 + 4N_2$				
100 0	7.82	5		
50 50	7.98	15		
25 75	8.2	15	Sphere, V_{240}	
12.5 87.5	8.2	25	$T_{init.}$ = 17°C	([67])
8 92	8.5	25–30	$P_{init.}$ = 50	
4 96	8.5	30		
0 100	8.4	180		

* Calcd. to $T_{init.}$ = 15°.

C_2H_2 Acetylene

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.	Lit.
$C_2H_2 + 2\frac{1}{2}O_2$	14.45		Cyl., V_{4000}	(9, 15)
$C_2H_2 + 2\frac{1}{2}O_2$		1.94	Cyl., V_{300}	(11)

C_2H_4 Ethylene

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.	Lit.
$C_2H_4 + 3O_2$	15.25		Cyl., V_{4000}	(9, 15)
$C_2H_4 + 3O_2$	14.18	2.86	Cyl., V_{300}	(11, 14)
$C_2H_4 + 3O_2$	15.73	2.23	Cyl., V_{4000}	(11, 14)

C_2H_6 Ethane

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.	Lit.
$C_2H_6 + 3\frac{1}{2}O_2$	15.30		Cyl., V_{4000}	(9)
$C_2H_6 + 3\frac{1}{2}O_2$		0.83	Cyl., V_{300}	(11)
% C_2H_6 in air				
3.05	3.8		Deduced from a published curve	(56)
3.3	4.9			
3.6	5.75			
4.05	6.85			
4.8	7.8			
5.6	8.3			
6.7	8.75			

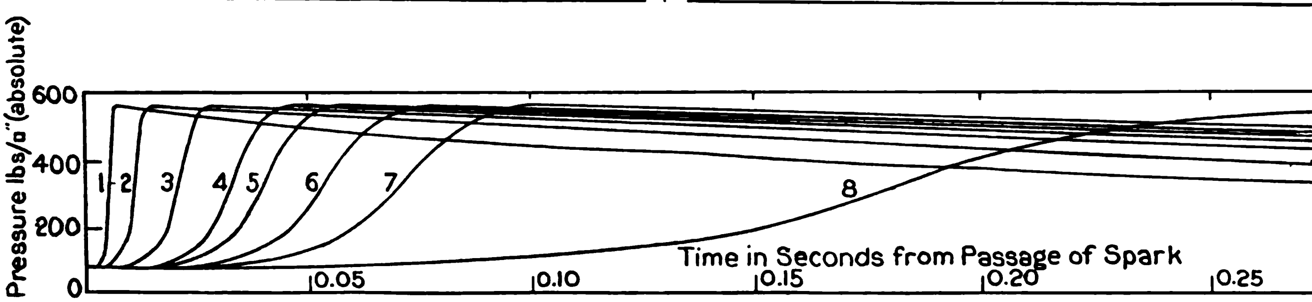

FIG. 22.—Time-pressure curves obtained from the explosion of $2(xH_2 + yCO) + O_2 + N_2$ mixtures. Initial pressure, 5 atm. Initial temperature, 50°C. Cylindrical vessels 7" in diam., 8" deep (83)

Curve	1	2	3	4	5	6	7	8
H_2	100	50	25	12	8	4	2.2	0.2
CO	0	50	75	88	92	96	97.8	99.8

CH_4 Methane

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.	Lit.
CH_4				
$+1.84O_2$	14.35		Cyl., V_{4000}	(13)
$+2.8O_2 + 10.5N_2$	7.9			
$+1.92O_2 + 7.24N_2$	8.95			
$+1.44O_2 + 5.41N_2$	7.98			
$+2O_2$	15.44		Cyl., V_{4000}	(9, 15)
$+2O_2$	13.94	1.24	Cyl., V_{300}	(11, 14)
$+2O_2$	14.81		Cyl., V_{4000}	(11, 14)
$+O_2 + 4N_2$	5.6	80	Sphere, V_{240}; $P_{init.}$ = 50 $T_{init.}$ = 17°C	(53)
% CH_4 in air				
6.30	4.20		Sphere, V_{4000}; highly polished interior surface	(54)
6.80	6.10			
7.45	6.64			
7.95	7.09			
8.45	7.40			
9.20	7.73			
9.40	7.80			
9.65	7.90			
10.10	7.97			
10.25	7.97			
10.75	7.87			
11.40	7.73			
12.10	7.36			
12.90	6.78			
13.40	4.80			
13.90	3.50			
6.05	3.86		Sphere, V_{16000}; highly polished interior surface	(54)
6.85	5.35			
7.80	6.85			
8.80	7.66			
9.80	7.94			
10.80	7.80			
11.90	7.40			
12.80	6.78			
12.1	8.15*	275.9	$T_{init.}$ = 100°C Cyl., V, 7 in. diam., 8 in. deep $P_{init.}$ = 6.5	(83)
11.0	8.56*	140.6		
10.5	8.69*	119.3		
9.9	8.70*	105.8		
9.7	8.77*	106.5		
8.5	8.19*	128.8		
7.3	7.20*	225.9		

* Calcd. to $T_{init.}$ = 15°. *See also* p. 177.

C_2H_6O Methyl Ether

$C_2H_6O + 3O_2$	18.82		Cyl., V_{4000}	(9)

$C_4H_{10}O$ Ethyl Ether

$C_4H_{10}O + 6O_2$	15.42		Cyl., V_{4000}	(9)

C_2N_2 Cyanogen

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.	Lit.
C_2N_2				
$+ O_2 + 4N_2$	10.95		Cyl., V_{18}	(2)
$+2O_2$	19.80		Cyl., V_{4000}	(9, 15) Cf. (5, 13)
$+N_2 + 2O_2$	16.72			
$+2N_2 + 2O_2$	13.93			
$+4N_2 + 2O_2$	11.66			
$+O_2$	23.72			
$+\frac{1}{2}N_2 + O_2$	19.52			
$+2N_2 + O_2$	14.42			
$+4N_2 + O_2$	11.14			
$+4NO$	16.00			
$+N_2O$	21.40			
$+2NO$	22.08			
$+2N_2O$	24.6			
$+O_2$		1.06	Cyl., V_{300}	(11)
$+2O_2$		1.55	Cyl., V_{300}	(11)
$+2O_2$		4.50	Sphere, V_{1500}	(11)
$+2O_2 + 2N_2$		15.4	Cyl., V_{300}	(11)
$+2O_2 + N_2$		6.09	Cyl., V_{300}	(11)
$+O_2 + \frac{3}{4}N_2$	18.65	3.20	Cyl., V_{300}	(11)
$+O_2 + \frac{1}{4}N_2$	21.09	2.74	Sphere, V_{1500}	(11)
$+O_2 + 3N_2$	13.88	10.35	Cyl., V_{300}	(11)
$+O_2 + 3N_2$	15.56	15.12	Sphere, V_{1500}	(11)
$+O_2 + 3N_2$		23.63	Cyl., V_{300}	(11)
$+O_2 + 4N_2$	10.6	29.78	Cyl., V_{300}	(11)
$+4N_2O$		4.53	Cyl., V_{300}	(11)
$+4N_2O$	12.02		Sphere, V_{1500}	(11)

C_6H_6 Benzene (82)

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.
16.84	8.28	105.1	$T_{init.}$ = 100°C $P_{init.}$ = 95 lbs./in.^{2} Cyl., V, 7 in. diam., 8 in. deep
14.76	9.00	73.5	
13.24	9.50	59.7	
13.16	9.50	59.8	
12.06	9.74	55.1	
10.7	9.78	49.0	
9.15	Loud metallic knock		

C_6H_{14} Hexane (82)

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.
16.91	8.86	91.2	$T_{init.}$ = 100°C
14.80	9.48	69.5	$P_{init.}$ = 95 lbs./in.²
13.97	9.56	64.0	Cyl., V, 7 in. diam.,
13.20	9.50	58.6	8 in. deep
10.72	Violent explosion		

Petrol (82)

Ratio air/fuel by wt.	$\frac{P_{max.}}{P_{init.}}$*	Milli-sec	Exper. condn. $P_{init.}$ lbs./in.²	
19.2	7.74	175.2	95.2	
16.9	8.58	109.6	95.5	$T_{init.}$ = 100°C
	8.52	110.8	142.5	Cyl., V,
14.8	9.33	78.4	95.5	7 in. diam.,
13.0	9.71	67.1	95.7	8 in. deep
10.7	Loud metallic knock		95.3	

* Calcd. to $T_{init.}$ = 15°C.

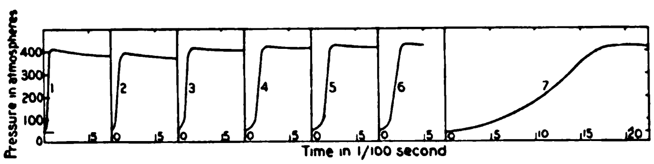

Fig. 23.—Time-pressure curve obtained from the explosion of $2(xH_2 + yCO) + O_2 + 4N_2$ mixtures. Initial pressure, 50 atm., room temperature. Spherical vessel, 240 cc capacity (67, 71).

Curve	1	2	3	4	5	6	7
H_2	100	50	25	12.5	8	4	0
CO	0	50	75	87.5	92	96	100

Influence of Temperature and Pressure

Mixture: 9.9% CH_4 in air. Cyl. V, 7 in. diam., 8 in. deep

$T_{init.}$ °C	$P_{init.}$ lb./in.²	$\frac{P_{max.}}{P_{init.}}$	$\frac{P_{max.}}{P_{init.}}$	Milli-sec
24.7	30.3	8.32	8.57*	99.7
24.7	53.0	8.41	8.65*	11.63
100	38.1	6.79	8.51*	79.8
100	66.7	6.79	8.52*	104.7
100	95.0	6.95	8.71*	109.0
200	48.2	5.60	8.57*	68.2
200	84.4	5.65	8.64*	75.0
200	120.6	5.66	8.69*	83.8
300	58.2	4.68	8.36*	49.6
300	102.3	4.75	8.48*	59.7
300	145.9	4.80	8.57*	67.1
400	68.5	4.12	8.30*	41.0
400	120.1	4.12	8.30*	47.3
400	171.5	4.19	8.56*	54.8

* Calcd. to $T_{init.}$ = 15°C.

Effect of Initial Temperature and Pressure
Petrol, Hexane and Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in.²	Pressure rise (lbs./in.²) ratio air/fuel by wt. Petrol	Hexane	Benzene
		13	14	12
100	100	660	668	680
	50	321	324	327
200	100	519	520	523
	50	250	250	248

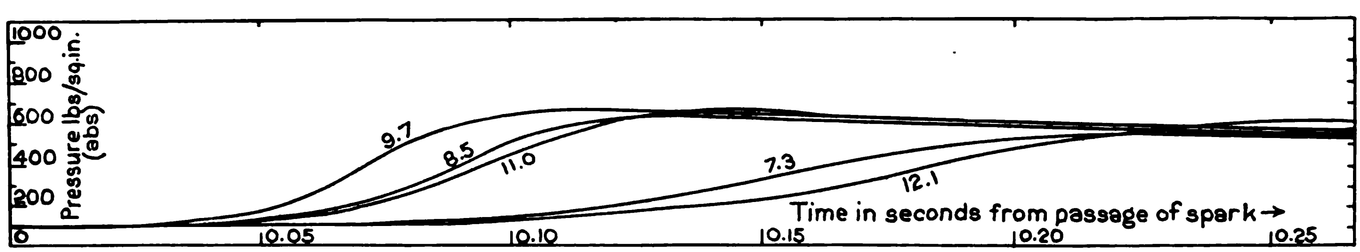

Fig. 24.—Time-pressure curves obtained from the explosion of methane-air mixtures. Initial pressure, 95.1 lb./in.² Initial temperature, 100°C (83).

Effect of Initial Temperature and Pressure
C_6H_6 Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in.²	Maximum pressure rise (lbs./in.²) ratio air/fuel by wt. 12.0	10.7	9.15
100	95.0	645	644	
	67.0	447	449	
	38.0	242	248	241
200	120.5	636		646
	84.5	438		442
	48.2	238		240
300	146.0	614		633
	102.0	420		434
	58.0	226		237

Measurements of Explosion Temperatures

Temperature Distribution at Moment of Maximum Pressure

Ten per cent coal gas (680 BTU/ft.³) (31). Vessel (Fig. 25): Capacity 6.2 ft.³

Mean temperature (inferred from pressure) . . . . 1600°C
(a) Temperature at center near spark (B) . . . . 1900°C
(b) Temperature 10 cm within wall (C) . . . . 1700°C
(c) Temperature 1 cm from wall (D) . . . . 1100°–1300°C
(d) Temperature 1 cm from wall (at the side) . . . . 850°C

Temperature Distribution 0.5 sec after Maximum Pressure

Mean temperature throughout the gas . . . . 1100°C
Mean temperature of gas excluding a layer 1 cm thick in contact with the walls . . . . 1160°C

Direct Measurement of the Temperature-cycle in a Gas Engine ([47]); *cf.* ([18, 20, 38])

Coal gas (460 BTU/ft.³); cylinder 7 in. diameter; stroke 15 in.; working volume 577 in.³; thermocouple: 10% alloys of Pt-Rh and Pt-Ir (0.0005–0.0008 in. thick).

No.	1	2	3	4	5
Ratio Air/ Gas	7.35/1	7.08/1	7.13/1	6.71/1	5.66/1
Jacket outlet, °C	35.6	37.2	81.4	40.6	52.8
Angle of crank	Temp., °C	Temp., °C	Temp., °C	Temp., °C	Temp., °C
360	569	568	582	705	636
300	496	503	515	624	540
240	349	348	371	517	431
180	256	269	317	422	371
120	217	223	262	365	330
60	228	241	273	326	337
30	267	275	330	339	442
720					2249
710				1947	
709					
708				1889	
705		1848	1871		1918
697	1836				
690	1546	1551	1532	1579	1721
675	1423	1418	1397	1437	1586
660	1154	1147	1269	1247	1417
645	1159	1124	1139	1193	1275
630	1041	1052	1018	1098	1192
615	1022	1007	1017	1058	1124
600	1017	975	975	982	1068
540	856	843	816	895	889
480	726	708	704	794	764
420	648	646	637	751	705

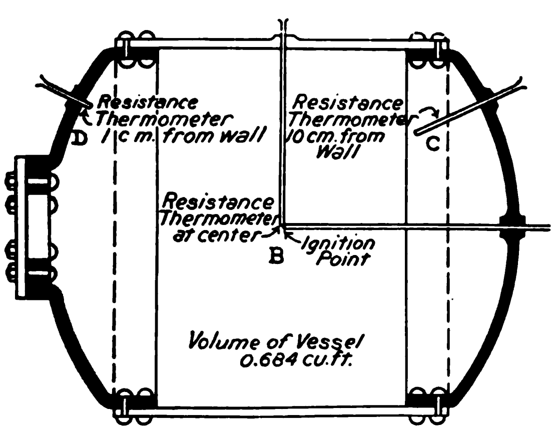

Fig. 25.—Explosion vessel.

Radiation Losses

Pressure-time curves obtained from the explosion of a 15% coal gas (675 BTU/ft.³)—air mixture in an explosion vessel: (*a*) with a highly polished, (*b*) with a blackened interior surface ([44]); volume of vessel 0.788 ft.³; area of interior surface 4380 cm².

Maximum pressure for initial pressure 1 atmosphere	Pressure lb./in.² for seconds after ignition			
	0.15	0.25	0.35	0.45
(a) 114.0 lb./in.²	98.7	84.2	73.5	64.9
(b) 110.8 lb./in.²	89.2	73.1	61.3	53.5

Same for 9.8% coal gas (575 BTU/ft.³) ([45]). Vessel as above

Time from ignition	Mean temperature °K, inferred from pressure	Mean radiation received per cm² of wall	Total loss of heat by radiation, % heat of combustion
0.15	1600	0.12	5.0
0.18	1700*	0.17	7.0
0.20	1680	0.21	8.7
0.25	1600	0.28	11.6
0.50	1280	0.46	19.0
0.75	1085	0.54	22.3
1.00	950	0.57	23.6

* Maximum temperature.

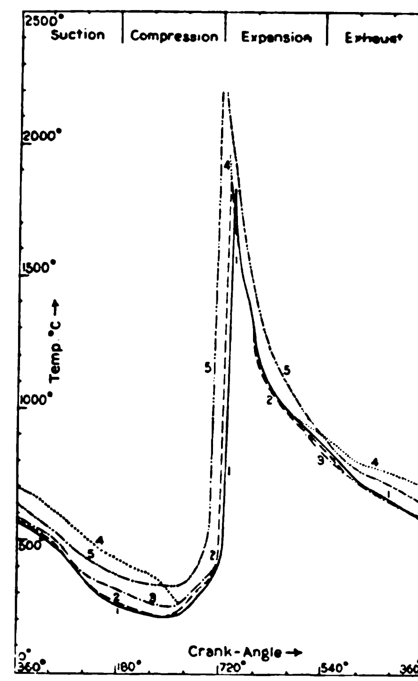

Fig. 26.—Direct measurement of temperature-cycle in a gas engine ([47]).

Influence of Density of Gas on Radiation Loss

Fifteen per cent coal gas (575 BTU/ft.³)—air mixture ([45])

Time from ignition, sec	Mean temperature °K, of gas (inferred from pressure)		Mean radiation received per cm² of wall		Total heat loss by radiation, % heat of combustion	
	P_i = ½ at.	P_i = 1½ at.	P_i = ½ at.	P_i = 1½ at.	P_i = ½ at.	P_i = 1½ at.
0.05	2270	2400	0.061	0.14	3.3	2.5
0.10	2020	2210	0.2	0.425	11.0	7.7
0.15	1790	2040	0.29	0.615	15.9	11.3
0.20	1600	1890	0.35	0.75	19.2	13.6
0.25	1440	1765	0.39	0.843	21.4	15.3
0.50	1030	1350	0.47	1.065	25.7	19.3
0.75	810	1140	0.49	1.143	26.8	20.7
1.00	700	1010	0.492	1.158	26.9	21.0

HYDROGEN—AIR MIXTURES (61)

Strength of mixture	Maximum temperature °K, developed (inferred from pressure)	Time of explosion (sec)	Total radiation received per cm² of wall	% heat of combustion lost by radiation up to max. pressure	Total heat loss by radiation, % heat of combustion
25.4	2400	0.017	0.60	0.5	16.1
15.3	1580	0.065	0.245	1.3	11.0
10.0	1230	0.240	0.12	1.4	8.2
Compared with coal gas					
15.0	2410	0.05	0.98	3.3	26.1
13.0	2170	0.07	0.81	3,7	25.0
9.8	1700	0.18	0.57	7.0	23.6

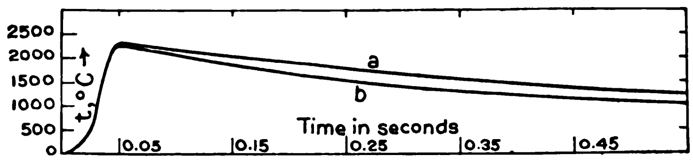

FIG. 27.—Pressure-time curves obtained from the explosion of a 15 % coal gas air mixture (44).

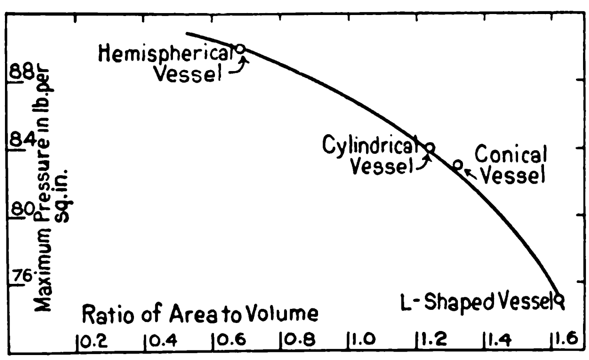

FIG. 28.—Influence of shape of explosion vessels having the same initial capacity on the maximum pressure developed (44).

HEAT LOSS

Mixture of 15% coal gas (570 BTU/ft.³) in air (64)

Sec*	Mean† gas temperature, °K	Heat loss/cm², % heat of combustion of the coal gas		
		Conduction	Radiation	Total
0.05	2440‡	5.1	3.8	8.9
0.1	2220	14.4	10.4	24.8
0.15	2020	20.3	15.0	35.3
0.2	1840	24.5	17.9	42.4
0.25	1710	27.7	20.3	48.0
0.3	1600	30.0	22.2	52.2
0.4	1430	34.4	24.3	58.7
0.5	1300	37.6	25.6	63.2

* Time after ignition in seconds.
† Inferred from pressure.
‡ Maximum temperature.

Various Formulae for Approximate Estimation of Cooling Losses in Explosions of Coal Gas—Air Mixtures

General formula for radiation loss in coal gas—air explosions (59)

$$R_T = 0.0001\ (T_{\max.} - 700\sqrt{D \times L})$$

where

R_T = Total radiation registered
$T_{\max.}$ = Maximum temperature (mean, °K)
D = Density of the gaseous mixture in atmospheres
L = Length of the explosion cylinder in cm

Rate of loss of heat by radiation, cm² of wall surface/sec (R_L) (64)

$$R_L = 1.75 \times 10^{-14}\theta^4$$

where

θ = mean absolute temperature.

For a cylindrical vessel (h cm diam. × h cm deep):

$$R_L = 0.32 \times 10^{-14}\theta^4\sqrt{h}.$$

Rate of loss of heat by conduction, cm² of wall surface/sec (R_L) (64):

$$R_c = 4 \times 10^{-13}\ (t - t_w)^4$$

for temperatures above 2000°K;

$$R_c = 7 \times 10^{-10}\ (t - t_w)^3$$

for temperatures below 2000°K where $(t - t_w)$ is the temperature difference, °C, between the hot gases and the walls of the explosion vessel.

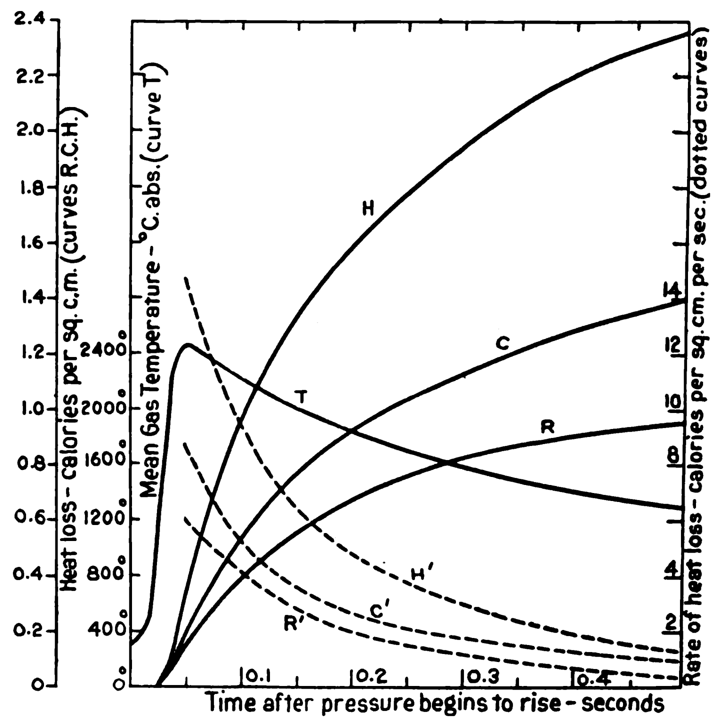

FIG. 29.—Heat loss from 15 % mixture of coal gas and air (64, 74). R = mean loss of heat by radiator per cm² of wall surface. C = mean loss of heat by conductor per cm² of wall surface. H = total heat loss. R′, C′ and H′ give the *rate* of heat loss by radiation, conduction and total loss, respectively. T = mean gas temperature (deduced from the pressure).

Rate of total heat loss, cm² of wall surface/sec (H_T) in a cylinder (h cm diam. × h cm deep) (64):

$$H_T = 4 \times 10^{-13}\ (T - T_w)^4 + 0.32 \times 10^{-14}\ T^4\sqrt{h}$$

for temperatures above 2000°K;

$$H_T = 7 \times 10^{-10}\ (T - T_w)^3 + 0.32 \times 10^{-14}\ T^4\sqrt{h}$$

for temperatures below 2000°K.

Total heat loss to walls of cylindrical explosion vessel (30 cm × 30 cm up to moment of maximum pressure (64) (coal gas—air explosions) at atmospheric density:

$$H_{\max.} = 2.15 \times 10^{-8}\theta^{2.5}_{\max.} \times t_e$$

or expressed as a proportion of the heat of combustion

$$H_{c\ \max.} = 1.43 \times 10^{-5}\theta^{1.5}_{\max.} \times t_e$$

where t_e is the explosion time.

Total heat loss per unit area in similar engines working under similar conditions may be given by the equation (74):

$$H = C + R\sqrt{d}$$

where

C = conduction loss per unit area
$R\sqrt{d}$ = radiation loss per unit area in an engine of diameter d.

Influence of Turbulence

Explosions of coal gas—air mixtures in conical vessel, capacity 115 in.[3] (ignition at vertex) (68); *cf.* (7, 31, 39, 56, 75)

Ratio air/coal gas	$P_{max.}/P_{init.}$ With turbulence	$P_{max.}/P_{init.}$ Quiescent	Milli-sec With turbulence	Milli-sec Quiescent
2.08	6.92		70.0	
2.61	7.23	6.44	28.0	95.0
3.13	7.48	6.68	39.0	71.0
3.65	7.24		38.0	
4.17	6.70	6.30	51.6	83.0
5.21	6.13	5.52	49.6	139.0
6.25	5.53	4.70	81.0	329.0
7.29	4.84	3.76	136.0	942.0
8.33	4.15		344.0	

Ethane, C_2H_6, and air mixtures in spherical vessel, capacity 4000 cm³ (sparked at center) (56)

% C_2H_6 in air	Milli-sec Quiescent	Milli-sec Turbulence
3.30		176
3.45		96
3.60	332	
3.80	152	
3.85	146	45
4.05	124	36
4.30		33
4.35	94	
4.60		26
4.65	73	
4.70		29
4.80	70	
5.00	63	24
5.25		21
5.35	54	20
5.60	52	
5.95		19
6.00	46.5	
6.40		19
6.45	46	
6.75	46.5	19
7.05	50	20
7.15	52	

Distribution of Energy at the Moment of Maximum Pressure

Coal gas—air explosions (64)

Internal Thermal Energy.—From 72% of the heat of combustion in a 9.7% coal gas—air mixture to 80% in a 15% mixture.

Available Chemical Energy.—About 10% in each case.

Heat Loss to Walls of Vessel.—From about 10% in a 15% mixture to about 18% in a 9.7% mixture.

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ANIMAL AND VEGETABLE OILS, FATS AND WAXES

C. Ainsworth Mitchell

INTRODUCTION

The General Property Table.—In Table 2, the oils and fats are first classified according to the Alder Wright system. Under each class, the individuals are arranged in alphabetical order of their generic names; and each individual is given a *General Index No.* by means of which it is identified in all subsequent tables. Where only one series of values is given, the data are usually those recorded for a single specimen of the particular oil. Table 2 serves therefore as a general finding table based upon the scientific names. If the scientific name is not known to the reader, he should first consult Table 1 and obtain the General Index No.

Supplementary Tables.—Properties not covered by Table 2 are set forth in Tables 3 to 17 inclusive.

Property-Substance Tables.—In these tables (Tables 18 to 27, inclusive) the individuals are arranged by index number in ascending order of the value of the property, the intervals on the scale of property values being indicated in bold-face type. These property-substance tables may be used (1) to select an individual having any desired value of a given property, or (2) to identify (in some cases at least) an individual by means of its properties. For the latter purpose, the properties cited in the following example are most useful.

Example; An oil is found by test to have the following properties: Congealing point, 0°; saponification, 190; iodine, 82; acetyl,

INTRODUCTION

Table des propriétés générales.—Dans la Table 2, les huiles et les graisses sont d'abord classées suivant le système d'Alder Wright. Dans chaque classe, les huiles et graisses sont rangées suivant l'ordre alphabétique de leurs noms génériques et on leur a attribué un "numéro index général" au moyen duquel elles seront identifiées dans toutes les tables suivantes. Où on a donné seulement une serie de valeurs, les données sont généralement ceux d'un seul échantillon de l'huile particulière. La Table 2 est donc une table de recherche générale, basée sur les noms scientifiques. Si le nom scientifique n'est pas connu du lecteur, il devra d'abord consulter la Table 1 afin d'obtenir le "numéro index général."

Tables supplémentaires.—Les propriétés qui ne sont pas mentionnées dans la Table 2 sont contenues dans les Tables 3 à 17 inclusivement.

Tables des propriétés des substances.—Dans ces tables (Tables 18 à 27 inclusivement), les huiles et graisses représentées par leur nombre index sont arrangées suivant l'ordre ascendant de la valeur de la propriété, les intervalles de l'échelle des valeurs de la propriété étant indiqués en caractères gras. Ces tables des propriétés des substances peuvent être utilisées: 1) pour choisir une huile ou graisse possédant une valeur désirée d'une propriété donnée, ou 2) pour identifier (au moins dans quelques cas) une huile ou graisse au moyen de ses propriétés. On se servira alors de

11; unsaponifiables, 0.6; fatty acids, M. P., 28°; "titer," 21°; n_D^{25}, 1.466. From each of Tables 20, 23, 22, 21, 26, 27 and 16*B*, write down a list of the General Index Nos. lying in the neighborhood of the experimental value and arrange each list in ascending order of these numbers. Determine the number of times each Index No. occurs in this set of lists. For the present example, this gives the following result: 8 times, No. 8; 7 times, No. 31; 4 times, Nos. 3, 5, 26, 47, 62, 91; 3 times, Nos. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

By turning to Table 2 and examining the properties there recorded for these oils, all but Nos. 8 and 31 are definitely eliminated. The oil under examination must, therefore, be either olive oil or neat's foot oil, or some oil closely resembling these but not included in Table 2. A further comparison of Nos. 8 and 31 results in the elimination of No. 31 on the basis of the acetyl and iodine values, but additional confirmatory tests are necessary.

Definitions.—*v.* p. viii.

EINLEITUNG

Die Haupteigenschafts Tafel.—In der Tafel 2 werden die Öle und Fette zuerst entsprechend dem Alder Wright System klassifiziert. In jeder Klasse sind die einzelnen Fette und Öle in alphabetischer Ordnung mit deren Gattungsnamen angeordnet, wobei jedem eine "General Index No." zu geordnet ist mit der es in den folgenden Tafeln erkannt werden kann. Ist nur eine Serie von Werten angegeben, so beziehen sich diese gewöhnlich auf eine einzelne Probe des bezeichneten Öles. Tafel 2 dient daher allgemein zum Nachschlagen, mit den wissenschaftlichen Namen als Grundlage. Ist dem Leser der wissenschaftliche Name nicht bekannt, so wäre zuerst die Tafel 1 heranzuziehen, wo die General Index No. erhalten wird.

Ergänzende Tafeln.—Eigenschaften die sich nicht in der Tafel 2 vorfinden, sind in den Tafeln 3 bis einschliesslich 17 enthalten.

Eigenschafts Tafeln.—In diesen (Tafel 18 bis einschliesslich 27) sind die einzelnen Öle und Fette nach ihren Index Nummern in aufsteigender Ordnung ihrer Eigenschaftswerte gereiht, wobei die Intervalle an der Skale der Eigenschaftswerte durch hervorgehobene Schrift angezeigt werden. Diese Eigenschafts Tafeln wären zu benützen:1) Um ein besonderes Öl oder Fett heranzuziehen, welches ihrgend einen gewünschten Wert einer gegebenen Eigenschaft hat. 2) Zur Erkennung (wenigstens in einigen Fällen) eines besonderen Öles oder Fettes auf Grund seiner Eigenschaften. In diesem zweiten Falle ist es am nützlichsten die Eigenschaften in der Art des folgenden Beispieles festzulegen.

Beispiel: Von einem Öl wurden durch Untersuchung folgende Eigenschaften gefunden: Erstarrungspunkt 0°; Verseifungszahl 190; Jodzahl 82; Azetylzahl 11; Unverseifbares 0,6; Fettsäure: Sm. P. 28°; Erstarrungs-Punkt 21°; $n_D^{25} = 1{,}466$. Aus jeder der Tafeln, 20, 23, 22, 21, 26, 27; und 16*B* schreibe man eine Liste der General Index Nummern heraus, welche in der Nähe der experimentell bestimmten Grösse liegen, wobei in der Liste die Nummern in aufsteigender Reihenfolge anzuordnen sind. Dann bestimmt man wie oft jede einzelne Index Nummer in der Liste anzutreffen ist. Für das vorliegende Beispiel bekommt man als Ergebnis: 8 mal No. 8, 7 mal No. 31, 4 mal No. 3, 5, 26, 47, 62, 91, 3 mal No. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Verwendet man die Tafel 2 und prüft die für diese Öle hier angegebenen Eigenschaften, so findet man, dass bis auf No. 8 und No. 31, alle anderen ausscheiden. Das gesuchte Öl ist daher entweder Olivenöl oder Klauenöl, oder ihrgend ein Öl, welches den genannten zwei sehr eng verwandt sein muss und nicht in der Tafel 2 enthalten ist. Ein weiterer Vergleich von No. 8 und No. 31 gibt, dass No. 31 auf Grund der Azetyl- und Jodzahl wegfällt. Besondere bestätigende Untersuchungen sind jedoch notwendig.

Definitionen.—*v.* p. viii.

préférence des propriétés citées dans l'exemple suivant, qui sont les plus utiles pour atteindre ce but.

Exemple: On a trouvé expérimentalement qu'une huile possède les propriétés suivantes: point de congélation 0°; indice de saponification, 190; indice d'iode, 82; indice d'acétyle, 11; insaponifiable 0,6; acides gras Pt. F., 28°, Pt. S., 21°; n_D^{25}, 1,466. On consulte alors les Tables 20, 23, 22, 21, 26, 27 et 16*B* et on dresse pour chacune des tables la liste des "numéros index général" qui se trouvent dans le voisinage de la valeur expérimentale, en disposant dans chaque liste ces numéros dans l'ordre ascendant. Ensuite on détermine combien de fois chaque numéro index se trouve dans l'ensemble des différentes listes. Pour l'exemple indiqué, on obtient les résultats suivants: 8 fois le No. 8; 7 fois le No. 31; 4 fois les Nos. 3, 5, 26, 47, 62, 91; 3 fois les numéros 13, 20, 29, 33, 54, 61, 67, 83, 84 et 92.

En se référant à la Table 2 et en examinant les propriétés qui y sont mentionnées relativement à ces huiles, on peut éliminer tous les numéros à l'exception des Nos. 8 et 31. L'huile à déterminer doit donc être ou de l'huile d'olive, ou de l'huile de pied de boeuf, ou une huile présentant une ressemblance étroite avec celles-ci, mais non mentionnée dans la Table 2. D'une comparaison ultérieure des Nos. 8 et 31, il résulte l'élimination du No. 31, sur la base les indices d'acétyle et d'iode, mais des essais supplémentaires confirmant la chose sont nécessaires.

INTRODUZIONE

Tabella delle proprietà principali.—Nella Tabella 2 gli olii ed i grassi sono anzitutto classificati secondo il sistema di Alder Wright. In ogni classe essi sono disposti in ordine alfabetico in base al nome comune, e ad ognuno è assegnato un numero indice che serve a riconoscerlo nelle tabell successive. Data una sola serie di valori, questi sono in generale quelli di uno solo campione del olio particolare. La Tabella 2 serve perciò come tabella generale di riscontri in base ai nomi scientifici. Se il lettore non conosce il nome scientifico, deve consultare prima la Tabella 1 dove trova il numero indice.

Tabelle supplementari.—Le proprietà che non si trovano nella Tabella 2, sono contenute nelle tabelle da 3 a 17 inclusa.

Tabelle delle proprietà.—In queste (da 18 a 27 inclusa) i singoli olii e grassi sono disposti nell'ordine crescente delle loro proprietà in base ai numeri indici: gli intervalli nella scala dei valori delle proprietà sono indicati con caratteri in grassetto.

Queste tabelle di proprietà possono servire: 1) per scegliere una sostanza che abbia un determinato valore di una certa proprietà, oppure, 2) per identificare (in alcuni casi almeno) una sostanza in base alle sue proprietà. A questo ultimo scopo sono sopratutto utili le proprietà citate nel seguente esempio.

Esempio.—Si sia trovato che un olio ha le seguenti proprietà: Punto di congelamento 0°; numero di saponificazione 190; numero di iodio 82; numero di acetile 11; insaponificabile 0,6; punto di fusione degli acidi grassi 28°, punto di solidificazione 21°; n_D^{25}, 1,466.

Da ognuna delle Tabelle 20, 23, 22, 21, 26, 27 e 16*B* si ricava allora una lista di numeri indici con valori delle proprietà vicini a quelli sperimentali e si dispone ogni lista con questi valori in ordine crescente. Si osserva quindi quante volte ogni numero indice figura in questa serie di elenchi. Nel caso presente si ha: 8 volte il numero 8; 7 volte il numero 31; 4 volte i numeri 3, 5, 26, 47, 62, 91; 3 volte i numeri 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Se ora si considera la Tabella 2 e si esaminano le proprietà ivi riportate per questi olii, essi vengono ad essere tutti scartati tranne i numeri 8 e 31. L'olio in esame perciò deve essere olio di oliva, oppure olio di piede di bue, o un olio che rassomiglia molto a questi due, ma che non è compreso nella Tabella 2.

Confrontando ancora i numeri 8 e 31, si scarta pure il 31 in base ai numeri di acetile e di iodio.

E' necessario però confermare ulteriormente questo risultato.

1. INDEX OF COMMON NAMES

English

(In the following index the word "oil" has been omitted. The various entries are oils unless specifically classified as "fats," "waxes," etc.)

French

(Dans la table suivante, le mot "huile" n'est pas mentionné. Les diverses références sont des huiles à moins qu'elles ne soient spécifiées comm "graisses" "cires," etc.)

German

(In dem folgenden Index wird das Wort "Öl" meistens ausgelassen. Die verschiedenen Bezeichnungen gelten Ölen, wenn sie nicht besonders mit den Namen "Fette," "Wachse," etc. bezeichnet sind)

Italian

(Nell'indice seguente è stata omessa la parola "olio." I diversi prodotti sono olii, tranne che non sia esplicitamente dichiarato che si tratta di "grassi," "cere," ecc.)

2. SCIENTIFIC NAMES AND COMMON PROPERTIES

Non-drying Vegetable Oils of the Olive Oil Type

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed; R = rhizome; n = refractive index

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
0.5	*Abelmoschus moschatus* (S)	0.917–0.918			195	95		96		0.3			
1	*Amygdalus Persica* (S)	0.918–0.925	−20	1–1.5	191–193	92–99.7	6.5	94–96				13–13.5	69
2	*Anacardium occidentale* (S)	0.918		1.45	194–200	79.5			0.6	1.5			61
3	*Arachis hypogaea* (S)	0.917–0.926	3	0.8	186–194	88–98	3.5	95	0.4	0.5–0.9		30.5–39	66
3.5	*Camellia oleifera* (S)	0.916–0.9227	−12		180–196	80–90		93–96	0.8–1		21–30		
4	*Carapa Guianensis* (S)	0.912–0.923	4.5		188–195.6	58–65		92–93.7	2.5–3.3		38.8		43
5	*Corylus avellana* (S)	0.917	−17 to −18		191–197	87	3.2	95.5	0.99	0.5	22–25	19–20	52
5.5	*Cyperus esculentus* (R)	0.924	below 0		225	62–76							
6	*Lecythis zabucajo* (S)	0.895	4	3.19	173.6	76.6	44.8				37.6		77
7	*Moringa oleifera* (S)	0.912–0.920	7–8		185–189	109–112.6		95	0.5			37.8	60
8	*Olea Europaea sativa* (F)	0.915–0.920 *Cf.* Table 10	{+2 turbid; −6 deposit}	0.3–1.0	185–196	79–88	10.5	95	0.6–1.5	0.4–1.0	26–30	16.9–26.4	63
9	*Olea Europaea sativa* (S)	0.918–0.919		1–1.8	182–186	88							65
10	*Oriza sativa* (S)	0.920–0.927	−10	43–77.2	192–195.8	96.4–99.9		95.2		3			85
11	*Phoenix dactylifera* (S)		18.1		211	52.3		95.2	0.88				37
12	*Pistacia vera* (S)	0.913–0.919	−5 to −10		191	83 87		96			17–20	13–14	57
13	*Prunus amygdalus* (S)	0.914–0.921	−15 to −20	0.5–3.5	183.3–207.6	93–103.4	9.6	96.0	0.5	0.75	13–14	9.5–11.8	58
14	*Prunus Armeniaca* (S)	0.915–0.926	−17	3.5	191.4–198.2	100–108.7	12.2		0.2		2.3–4.5		70
15	*Prunus cerasus* (S)	0.918–0.929	−19 to −20	1.1	193.3–195	110–114.3					19–21	13–15	38
16	*Prunus domestica* and *P. damascena* (S)	0.912–0.913	−5 to −8	0.55	191–193	100–103.6					12.4–18		68
16.5	*Sterculia foetida* (F, S)	0.926			188–199	76–83		95–96	1.0			31–32	81.5
16.6	*Strophanthus hispidus* (S)	0.9249–0.9254	−6		188–195	96–102		92–95	0.5–0.9		32.2		
16.7	*Terminalia catappa* (S)	0.917–0.920	3–4		175–196	84–89		91–92			42–44		48.5
17	*Thea sasanqua* (S)	0.920	−5 to −12		190–194	91		91.5	0.1				54, 55
18	*Ungnadia speciosa* (S)	0.912	−12		191–192	81–82		94			19	10	

Non-drying Vegetable Oils of the Rape Oil Type

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
19	*Brassica juncea* (S)	0.916–0.921		3.7–7.2	172–180	102–108		95.5	0.33–0.89				78
20	*Brassica campestris* (S)	0.913–0.917	−10	0.36–1.0	168–179	94–105	14.75	94.5–96.3	0–0.79	1.48	18.5–20	11.7–13.6	82
21	*Brassica* (varieties of) (S)	0.916–0.919	−8		177–181	109–122				1.4–1.7		13.5–16.5	94
22	*Eruca sativa* (S)	0.916–0.919		2.5–3.7	169–174	97.5–102		95.5	0.75				80
23	*Raphanus sativa* (S)	0.916–0.918	−10 to −18		174–178			95.9	0.33		20	13–15	71
24	*Sinapis alba* (S)	0.912–0.916	−8 to −16	5.4	171–174	94–98.4		96–97			15–16		75
25	*Sinapis nigra* (S)	0.915–0.919		5.7–7.3	173–175	99–110		96		3.3	16–17	13.4–13.7	88
25.1	*Sinapis nigra* (Russian)	0.920			181–182	115–120							

Non-drying Vegetable Oils of the Castor Oil Type

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
26	*Jatropha curcas* (S)	0.919–0.924	{4.4 turbid; 2.8–2.9 solid}	0.5–5.0	192.5–210	98–110	9–25.3	95.2	0.28–0.48		24–30		67
27	*Ricinus communis* (S)	0.960–0.967	{−12 turbid; −17 to −18 solid}	0.12–0.8	175–183	84	146–150.5		1.4	0.6	13		110
28	*Vites vinifera* (S)	0.917–0.933	−10 to −17	0.75	171–191	94.3–135	13.5–14.5	92	0.46	1.6	23–25		89

Non-drying Animal Oils

L = lard; T = tallow; F = foot

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
29	*Oleum adipis* (L)	0.913–0.915	−2 to +4	{1.56 (0.1–2.5)}	193–198	62.5–79		97		0.6	33–38.4	27–33	45
30	*Oleum adipis bovis* (T)	0.914–0.919	2 to 7.5	0.2–0.25	193.5–199	56–60.5						35–37.5	
31	*Oleum pedis bovis* (F)	0.913–0.918	−2 to +10	0.1–0.6	193–199	57.5–75	7.7–9.3	94.8–95.9	0.9–1.2	0.12–0.65	29–41	16–26.5	47

Vegetable Semi-drying Oils

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
32	*Avena sativa* (G)	0.925		34.7–35.3	189.8–192.4	114.2		94.9		1.30–2.65	27.5		114
33	*Bertholletia excelsis* (K)	0.917–0.918	0 to 3	1.4	193	90–106					28–30	31.1–32.2	56
34	*Camelina sativa* (*Myagrum sativa*) (S)	0.923–0.927	−18		188	132–152					13–14	17–18	107

Vegetable Semi-drying Oils.— (*Continued*)

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
35	*Ceratotheca sesamoides* (S)	0.916		0.63	190.2	110.6							83
35.5	*Citrus aurantium* (S)	0.918–0.919			194–197	97–104		95–96	0.5–0.8				70.5
36	*Citrus limonum* (S)	0.916–0.918	−6		188.3	107.3	13.6	95.6	0.55			19.7–21.0	
37	*Croton tiglium* (S)	0.942–0.944	−8 to −18	27–30.9	193–215	108–109	19.8–38.6					17–19	115
37.5	*Cucumis melo* (S)	0.921_{25}^{25}		0.43	192.3	125.9	15.8	95.1	0.33	1.1			
38	*Cucurbita pepo* (S)	0.923–0.925	−15		188–193	121–130		96	4.45			26–28	95
39	*Eriodendron anfractuosum* (S)	0.923–0.933		3–15	189–194.5	78–93					38		64
40	*Fagus sylvatica F. Americana* (K)	0.922	−17		191–196	97–111		95–96			23–24		73
41	*Gossypium* species (S)	$0.917–0.918_{25}^{25}$	+12 to −13	0.6–0.9	194–196	103–111.3	21–25	95.7	0.95	1.1	34.5		
41.5	*Hydnocarpus alcalae*	0.948_{30}^{30}	24	6.7	202	94.0					55		143
42	*Hydnocarpus anthelmintica* (S)	0.949_{30}^{30}		0.6	206–209.8	84.5–90.8	21.8	95.5	1.02		46		122
42.1	*Hydnocarpus Hutchinsonii* (S)	0.943_{30}^{30}	23	5.3	199	83.5					43		
42.2	*Hydnocarpus subfalcata* (S)	0.951_{30}^{30}	21	6.6	206	89.0					41		140, 142
42.3	*Hydnocarpus venenata* (S)	0.947_{30}^{30}	20	1.2	191	90.7					47		145
42.4	*Hydnocarpus Wightiana* (S)	0.947_{30}^{30}	11	6.7	207	97.0					40		144
42.5	*Hydnocarpus Woodii* (S)		18	5.9	192	68.5					43		
43	*Lepidium sativum* (S)	0.920–0.924	−15		180–183	102–118		95.5	0.2–0.4		16–18		
43.5	*Luffa Ægyptica* (S)	0.9254		28.8	188	108.5		95	1.4				86.5
44	*Lycopersicum esculentum* (S)	0.922			187–192	107–125	11.4–20.5	95–96.6	0.1–0.3				97
45	*Madia sativa* (S)	0.921–0.933	−10 to −12		193–194	121–129		95.5			21.7	22–26	
45.1	*Pangium edule* (S)	0.925_{30}^{20}	7	6.9	200	78.5					18		137
46	*Quercus agrifolia* (S)	0.916	−10		199.3	100.0					25		
47	*Sesamum indicum* (S)	0.919_{25}^{25}	−4 to −6	9.8	188–193	103–117		95	1.1–1.2		25–35	23–32	87
48	*Soja hispida* (*Dolichos hispida*) (S)	0.924–0.927	−10 to −16	0.3–1.8	189–193.5	122–134	4.9	93–94.5	0.5–2.8	1.27–1.54	26.2–27.5		96
49*	*Taraktogenos Kurzii* (S)	0.943–0.954	20–25	0.79–21.5	196–218	97.6–110.4							130
50	*Triticum sativum* (Gm)	0.924–0.929	0 Viscous		183–190	115			2–3	2.4–2.6	39–40		100
51	*Zea mais* (S)	0.921–0.928	−10 to −20	1.37–2.02	187–193	111–128	7.5–11.5	93–95	4.3	1.5–2.8	17–20	14–16	86

Vegetable Drying Oils

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
52	*Aleurites cordata* (S)	0.934–0.940		3	194–197	150–158			0.39	0.4–0.8	30–49	36–39	149
53	*Aleurites Fordii* (S)	0.939–0.949		2	190–107	163–171			1.10	0.4–0.8			149
54	*Aleurites moluccana* (S)	0.925		2	189–195	163–164	9.8	95–96	1.2	0.5–0.9			111
55	*Aleurites montana* (S)	0.939–0.949		2	190–197	163–171			0.35	0.4–0.8			149
56	*Aleurites triloba* (S)	0.927			202–204	139–143.8						17.8	111
56.5	*Amoora rohituka* (S)	0.931–0.939		17.0	190–192	135		93.2	1.6		20–22	16–14	105.5
57	*Argemone Mexicana* (S)	0.925		6.0	188–190	120–122.5		95.1	0.0	1.14	22.8		91
58	*Cannabis sativa* (S)	0.928–0.934	−15 to −28	0.45	190–195	145–161.7				1.08	17–21	15.6–16.6	126
59	*Carthamus tinctorius* (S)	0.925–0.928		0.6	188–203	122–141	16.1	95	0–0.2		11–17	7–12	102
60	*Conepia grandifolia* (S)	0.969		5.7	188.6	179.5					21.5 (begins) 65.0 (ends)		148
61	*Guizotia oleifera* (S)	0.925–0.927	−8	0.95–2.94	189–192	126.4–133.8		95.4			25.4	22.6	
62	*Helianthus annuus* (S)	0.924–0.926	−17		188–193	129–136			0.5	0.31	22–24	18–19.8	108
62.5	*Hesperis matronalis* (S)	0.931–0.934	−22		192	135							
63	*Hevea Braziliensis* (S)	0.924–0.930			190–200	117–140	28	95.3	0.27–0.3			15–20	93
64	*Juglans nigra* (N)	0.918–0.921	−12 turbid	8.6–9.0	190.1–191.5	141–142.7		95.8			0		
65	*Juglans regia* (N)	0.925–0.927		2.5	190.1–197	139–150		93.4–95.4	0.92		15–20	14.3	113
66	*Lallemantia iberica* (S)	0.933^{20}	−25		185	162		93.3	1.55		22.2		
67	*Linum usitatissimum* (S)	0.930–0.938	−19 to −27	1–3.5	188–195	175–202		94.5–95.5	0.95	0.4–1.2	20–24	16–20.6	127, 128
68	*Manihot glaziovic* and *M. ceara* (S)	0.924–0.932	−17		188–192	117–139	21	94–96	0.4–3.0		23–26	20–24	90
68.5	*Oncoba spinosa* (S)	0.930		12.1	192.2	177.0				1.3			125

* *Oleum Chaulmoogrea* (U.S.P.X.): *d* 25, *ca.* 0.950; congeals below *ca.* 25°; sapon. value, 196–213; I value; 98–104; $[\alpha]_D^{25}$ 48–60°.

Vegetable Drying Oils.—(*Continued*)

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
69	*Papaver somniferum* (S)	0.924–0.926	−16 to −18	2.5	193–195	128–141		95.4	0.6	0.43	20.5	17–19	106
70	*Paulownia imperialis* (S)	0.935–0.940	below −17		193.4–196.3	149–158							150
71	*Perilla ocimoides* (S)	0.930–0.937			188–194	185–206		95.8			−5		133
72	*Pimento officinialis* (S)	0.923_{20}^{20}		0.03	171.4	134.4							
73	*Pinus abies* (S)	0.931	−26		192	120.5							101
74	*Pinus cembra* (S)	0.930–0.932	−20	1.5	191.8	150–159.2		93.27	2.0	1.3			116
75	*Pinus Gerardiana* (S)	0.931	−17		191–192	118–119					0		
76	*Pinus monophylla* (S)	0.933			189–192.8	101.3–108					19		72
77	*Pinus montana* (S)	0.932	−25		180–190	145–146		92			0		
78	*Pinus picea* (S)	0.921	−18 to −20		191	119–120					16–19	10–16	146
79	*Pinus pinea* (S)	0.928–0.933	−27		191–193	120–121		91–92				10–15	98
80	*Pinus sylvestris* (S)	0.932	−28 to −29		189.8	147.1							105
81	*Ricinodendron Rautannenii* (S)	0.928–0.930	−12 to −22		190–195	124–135		94–98	0.75		30–40		147
82	*Stillingia sebifera* (S)	0.940–0.946		1.24	209–210.4	145–161	28.7	94.4–95.2	0.93–0.99	1.45	14.5		135

Fish and Marine Animal Oils

F = whole fish; B = blubber; L = liver

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
83	*Alosa menhaden* (*Brevortia tyrannus*) (F)	0.923–0.933	−5		189–192.9	148–185			1.2	0.6–1.43			123
84	*Balaena mysticetus* and other species (B)	0.917–0.924	0 to −2	1.9	160–202	90–146	11–23	93–95	14	1–4	14–27	10–24	103
85	*Clupea harengus* (F)	0.920–0.939			170–194	102–149		95–96		1–2	30–32		112
86	*Clupea pilchardus*, *C. scombrinus* (F)	0.920–0.934	20–22		187.7–196	150–193	21–22	93.3–96	0.5–1	0.98	30–34.8	28.2	134
87	*Clupanodon melanostica* (F)	0.928–0.935		2.2	189–192.1	121.5–124.5		94.5–97		0.5–3	35–36	27.6–28.2	76
88	*Delphinus globiceps* (B)	0.908–0.930	+5 to −3		187.3	99.5		93.1	5.6	2			26, 49
89	*Delphinus phocaena* (B)	0.926			290 (Jaw) 203.4 (Body) 253.7–272.3 (J)	32.8 (J) 126.9 (Bo) 30.9–49.6 (J)		65.9 (J) 68.4–72.0 (J)	65.9 (J) 46.9 (Bo) 132 (J)	16–17 (J)			32
90	*Gadus merlangus* (L)	0.925–0.930			177–189	123–181		95	0.4–0.7	0.7–7	31		
91	*Gadus morrhua* (L)	0.922–0.931	−3	5.6	171–189	137–166	1.15	95.3	0.2	0.54–2.68	21.8–38	17.5–24.3	118
92	*Phoca species* (B)	0.915–0.926	3		187.5–196.2	130–152		93–96	0.2	0.3–1.0	22–23		109
93	*Selache* (*cetorhinus*) *maxima et al.* (L)	0.916–0.919			157–164	115–139	11.9	87–97		2.8–15.2	21–22		119, 121
94	*Squalus acanthias* (L)	0.918			169.7	126.4				8.4			92
94.5	Various species Japanese sharks (L)*	0.864–0.932		0.0–4.3	23–186	91–345				1–90	25–35		

*Extremes for 36 species ([188]).

Japanese salmon and trout oils: *see* Toyama, *142*, **26**: 273; 23. Liver oil of palm-crab, Kobayashi, *Ibid.*, 585.

Insect Oil

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
95	*Bombyx mori* (from pupae)	0.928	0	18.6–27.5	190–194	116.3–131.9	19.7	94.5	3.4	2.61	36.5	27–28	99

Vegetable Fats

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
96	*Acrocomia sclerocarpa* (F & K)	0.866^{100} (K)		55.8 (F) 0.4–4.7 (K)	189 (F) 237–255 (K)	77.2(F) 16–30 (K)			5.7–7.2 (K)		20.5–21 (K)		10
97	*Akebia quinata* (S)	0.934		25.4	246.4	78.38		85.8	39.76		31		22
98	*Allanblackia* (*Stearodendron*) *Stuhlmannii* (S)	$0.856–0.861^{100}$ 0.930	30.4–38	11.6–23	186.6–191.7	38.7–41.9					59	61.4–61.6	17
99	*Adansonia digitata* (S)	0.915–0.920	+3 to −3		190–192	56–79					35–38		19, 39
100	*Astrocaryum vulgare* (S)	0.867^{100} (K)	28.6 (K)	43.8 (F) 0.54–1.69 (K)	220.2 (F) 240–250 (K)	46.4(F) 12.2–13.9(K)			3. 8 (K)	0. 75 (F)	27 (K)		6
101	*Attalea cohune* (S)	$0.868–0.871^{100}$			254	11–13.7			8		27–28		3
102	*Attalea funifera* (S)	0.868^{100}	22.7	2.8	246.9	15.6–16.3			5.8				
103	*Attalea spectabilis* (S)	0.869^{100}	24.6	1.2	259.5	8.9			6.3	0.36	23.6		7

Vegetable Fats.—(*Continued*)

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
104	*Bassia butyracea* (S)				188–190.8	42.1–42.6		94.8–95.6	0.4–1.31	1.36	58.4		20
105	*Bassia latifolia* (S)	0.862^{100}	19–22		192.2–199.9	53.4–67.8		94.7–94.9	0.44–0.88		39–45	38–40	41, 46
106	*Bassia longifolia* (S)	$0.858–0.862^{100}$	36		188.4–189.8	60.4–62.4		94–95	1–2			38–41	
107	*Bassia Mottleyana* (S)	0.864^{100}		11.3	189–192	31.5		95.7	0.6–0.8	0.5	56		50
		0.917											
108	*Bassia toxisperma* (S)	0.858^{100}	21	9.27	180–188.6	57–65		94.5–95	1.1–2.5	3.86	49–52.8	47	53
		0.916											
109	*Blighia sapida* (S)	0.858^{100}	20	20.1	194.6	49.1		93	0.9		42–46	38–40	
110	*Buchanania latifolia* (S)	0.858^{100}		15	191.8–195.4	54.7–59.9		94.8–95.8	0.33				
111	*Butyrospermum Parkii* (S)	0.859^{100}	25–30	2.8	178–190	54–63		93.8–95.8	1.25–1.4	5–9	52–53		81
		0.917											
112	*Calotropis gigantea* (S)				196–197	84–85		95–96	0.5		33–34		62
113	*Calophyllum inophyllum* (S)	0.915			194	95.5		93.6	0.38			28–29	132
114	*Canarium commune* (S)	0.905^{40}			193–200	59–66	15–16	95–96	0.1		40–42	37–40	
115	*Canarium ovatum* (S)	0.907_{4}^{30}		1.42	197.4	55.9				0.19			
116	*Caryocarpus tomentosum*, etc. (S)	0.898_{15}^{40}	23–29		199.5	49.5	6.6	96.6	0.65		48.3–50	46–47	31
117	*Cocos butyracea, C. nucifera* (K)	0.926	14–22	2.5–10.0	253.4–262	6.2–10	2.3–6.9	82.3–90.5	6.6–7.5		24–27	21.2–25.2	1
		$0.864–0.868^{100}$											
118	*Cocos syagras* (S)		26.8	2.9–3.2	252.5	12.5–13.4							5
119	*Elaeis guineensis* (W. Africa) (F)	0.924		10	200–205	49.2–58.9	15.7	94.5–97	0.9–1.9		50	42.5–45.5	59
		0.858^{100}											
120	*Elaeis guineensis* (W. Africa) (S)	$0.866–0.873^{100}$			243–255	10.5–17.5	7.6	91–91.5	5–6.8		25–28.5	20–25.5	12
121	*Elaeis guineensis* (S. America) (F)		21.9	29.8–20.5	197	78.1–88.3							
122	*Elaeis guineensis* (S. America) (S)		27.4	0.55–0.33	220.2–231.4	25.5–31.6							
123	*Garcinia indica* (S)	0.853^{100}		14.5–21.0	186.8–191.3	25–34.2		94.6–95.6	0.11–1.54		60–61		29
124	*Gossypium* species (S)	$0.867–0.868^{100}$		4–10		88.7–93.6		96.5	0.22		27–45	39.9–51	79
125	*Isoptera borneensis* (S)	0.856^{100}		11.3	192.1	31.5		95.7	1.1	0.5	56		23
126	*Laurus nobilis* (F)	0.880^{100}			198–199	68–80			1.6				124
127	*Lindera praecox* (S)	0.935			274	20.5		89.2	1.39			13	2
128	*Lindera serica* (S)	0.940			255	65.3		86.2	2.53			9–10	
129	*Lindera triloba* (S)	0.936			282	11.6		85.7	2.0			14	
130	*Lophira alata; L. procera* (S)	0.901_{40}^{40}			180–194.6	60–78			0.8–0.9		42–49		
		0.859^{100}											
131	*Mafureira oleifera* (S)	0.857^{100}	25–37		199–221	40–47		93	1–4		51–55	48–52	
132	*Mangifera Jabonensis* (*Irringia Barteri*) (S)	0.860^{100}	27–35	4–10	241–245	29–31		94	0.2–0.4		35		4
133	*Maximiliana regia* (S)	0.867^{100}		0.33	240.9–253	13–16			3.0		24.2		9
134	*Melia azadirachta* (S)	0.925	35		185.6	72.9			8.27				51
135	*Myrica cerifera* (*M. Carolinensis*) (F)	0.995	39–43		205.5–211.7	3.9–9.5		92–94	0.5		47–48		8
		0.875^{100}											
136	*Myristica officinalis* (S)	0.945–0.996		17.2	154–178				1.1–4.2				
137	*Myristica otoba* (S)	0.892		16.8	185–199	20–54				20.4		37.2	117
138	*Myristica becuhyba* (S)	0.912	32–32.5		219–220	9–10		93–94			42.5–46		40
139	*Oenocarpus batava* (F)		7.0	0.48	191.8	78.2				1.1			48
139.5	*Oncoba echinata*	0.898^{100}		4.5	192.4	99.7				1.6			
140	*Palma Maripa* (K)	0.868^{100}	25.5–26		270.5	17.3		89	4–5		27–28		
141	*Pentaclethra macrophylla* (S)	0.912–0.921	14		182–186	87–101	21–37	94–96	0.6		50–57		74
142	*Pentadesma butyracea* (S)	0.869^{100}			186–197	45–49		95	0.3		57–60		25
143	*Pongamia glabra* (S)	$0.924–0.935^{40}$	8		178–185	78–94			1		44–45	36–42	131
144	*Rhus succedaneum* (F)	0.970–0.980	40.5–46	11–12	206.6–237.5	4.9–12.8	17.25–26.5	90–91		1.1–1.6	53–56.5		34
		0.875^{100}											
145	*Schleichera trijuga* (S)	0.924–0.942	10		215–230	48–55		91–91.5	9	3.1	52–55	49.7–50.7	42
146	*Stillingia sebifera* (S)	0.918–0.922	24–34	2.4	179–206	23–40.5		95.3	0.2–0.9		39–57	45.2–47.2	13
												50.9–52.5	
147	*Theobroma cacao* (S)	0.964–0.974		1.1–1.9	192.8–195	32.8–41.7	1.97	94–95	0.3–1		48–53	47.2–49.2	21
		0.858^{100}											
148	*Theobroma grandiflora* (S)	0.852^{100}		44.0	187.8	44.8			0.08	0.91		48.1	
149	*Vateria indica* (S)	0.915		5.8–15.3	188.7–192	37.8–39.1		95.1–95.2	0.2–0.4		56.6–57		35

Animal Fats

AT = Adipose tissue

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	n Finding No. v. p. 212
150	*Adeps* (AT)	0.934–0.938 $0.861^{100}_{15.5}$	27.1–29.9	0.5–0.8	195–203	47–66.5	2.6	93–95			37–46.6	36–42.4	24
151	*Adeps bovis*	0.895 0.862^{98}_{15}	31–38	0.25	196–200	35.4–42.3	2.7–8.6	96–96.5			42.5–44	37.9–46.2	
152	*Adeps ovis*	0.937–0.953 $0.858^{100}_{15.5}$			195–196	48–61					33.5–49	40–48.5	28
153	*Anser cinereus*	0.923–0.930	22–24		191–193	58–67		94.5–95.3	0.2–0.98		36.6–40	31–34	44
154	*Capellae lactis adeps*	$0.917–0.935^{37.7}_{37.7}$			233–236	25–37			20.8–27.7				14
155	*Cervus elephus*, etc.	0.962–0.967		0.8–5.3	194.5–200	26–36		95.8	0.68	0.52	50–64	46–50	
156	*Equus caballus*	0.919–0.933			195–200	75–86		95–98			31.3–53.4		84
157	*Gallus domesticus* (AT)	0.924 $0.906^{33.7}_{33.7}$	21–27		193–204.6	66–71.5	45	94.6	1.8		38–40	32–34	36
158	*Lepus cuniculus*	0.934–0.936 0.861^{100}_{15}			199–203	70–99.8		99.5	0.7–2.8		39–50	35–41	
159	*Sevum*	0.925–0.950			193–198	35–45		95–96	0.5–1.0			40–50	
160	*Sevum ossis*				190–196	50–55	11.3	94–95	0.2–1.7		42.5–44		
161	*Vaccae lactis adeps*	$0.907–0.912^{40}_{15}$			210–230	26–28 (Extremes 19.5–49.5)	1.9–8.6	87.6–89.6	17.0–34.5		38–41	33–39	15, 27, 30
	Sperm Oil												
162	*Hyperoodon rostratus*	0.880–0.881		0.4–0.5	123–134	80.4–82.0	4.1–6.4			36–41	10.3–10.8	8.3–8.6	11
163	*Physeter macrocephalus*	0.878–0.884			120–137	80–84	4.5–6.4				13.4		16
	Vegetable Non-glyceridic Waxes												
164	*Corypha cerifera* (exudation from leaves)	0.995–0.999		4-8	79–84	13.5	55.2			51-55			104
165	*Euphorbia anti-syphilitica*			17.0	51								33
166	Montan wax (lignite tar, lignite peat)			73	74	16				47			
	Animal Waxes												
167	*Adeps lanae* (sheep's wool)	0.970–0.973		59.8	82–130	17–29	23			39–44	41.8		141
168	*Apis indica* (bees)			6–6.1	82–83	10							18
169	*Apis mellifera* (bees)	0.961–0.968 $0.822–0.827^{98}_{15.5}$	60.5–62	16.8–20.6	88–96	8.8–10.7	15.2						18
170	*Apis* (Chinese bees)			5.3–9.7	90.2–120.2								18
171	*Coccus cerifera* (insect on leaves of *Fraxinus chinensis*)	0.809–0.811	80–81	63									
172	Spermaceti (oils of *Cetacea*)	$0.905–0.945^{99}_{15.5}$ $0.806–0.812^{99}_{15.5}$		0.5–2.8	126–135		2.6			51.5			

3. COMPOSITION TABLE

(In weight %)

General Index Number

Class 1. Non-drying Oils of Almond and Olive Oil Type

Glycerides principally of oleic acid. Linolic acid present in small proportion

0.5. *v.* (98.5).
1. Similar to No. 13.
2. Oil from kernels is non-drying. Olein, 80.4; stearin, 17.3 (48). The oil from the pericarp is black and has high iodine value (294) (202).
3. Palmitin, stearin, arachidin, lignocerin, olein, linolin and possibly hypogaein. The mixed lignoceric and arachidic acids (Renard's "arachidic acid") vary from 4.3 to 5.4 (av. 4.8); stearic acid *ca.* 5. Unsaturated acids *ca.* 30, of which *ca.* 60% is linolic (63). Hypogaeic acid not found (164) but occurrence considered probable (78). For variations in constants *v.* (100). "Unsaturated" fatty acids 75–79.5, with iodine value, 109–126 (100).

3.5. Similar to No. 17 (185).
4. Non-drying glycerides.
5. Oleic acid, 85; palmitic, 9.4; stearic, 1; glycerol, 10.4; phytosterol, 0.5 (76).

5.5. *v.* (19, 28.5, 150).
7. Glycerides of oleic, stearic and palmitic acids, and, according to Völker, behenic acid.
8. *Ca.* 25 solid and 75 liquid glycerides, mainly olein. Linolic acid, 7; oleic, 93 (80). No stearic acid (83). A mixed glyceride (1–2%, M. P. 53–55°), probably stearic, palmitic and oleic, has been isolated (92). Ultimate composition: C, 77.2; H, 11.3; O, 11.5 (163). Highly unsaturated acids, 78–93.5, with iodine value, 89–98 (100).
9. Similar to No. 8. Solid acids, 9.7 (of which stearic, 40; palmitic, 60); liquid acids, oleic and linolic; no arachidic (110).
10. Oil from commercial rice meal contains free fatty acids, 43–77 (168). Impure fat from polishings *v.* (68).
11. The constants indicate presence of oleic and volatile insoluble fatty acids. On the border-line between oils and solid fats.
12. Largely oleic glycerides.
13. Fatty acids, mainly oleic, with *ca.* 6 linolic (63). No linolenic. Little, if any, stearic (84).
14. Similar to No. 13 *cf.* (160).
15. Resembles No. 13, but has higher iodine value (110–114), indicating larger amount linolic acid. HCN present (141).
16. Similar to No. 13, but contains more linolic acid.

16.5. *v.* (32, 200).
16.6. *v.* (21.1).
16.7. *v.* (72).
17. Very similar to No. 8. 88–93 liquid acids with iodine value 99.6–104.4 (118). This commercial oil is distinct from tea oil (*Thea sinensis*) *v.* (184).

Class 2. Non-drying Oils of Rape Oil Class

19. Greater proportion unsaturated fatty acids than No. 20.
20. Mainly glycerides of rapic and erucic acids (159.5); linolenic acid present (63); arachidic and lignoceric acids *ca.* 1.43 (11). Yields *ca.* 1% insoluble bromide of mixed glyceride (84). "Unsaturated" acids 94–95, with iodine value, 100.5–105 (100).
21. Larger amount less saturated glycerides than No. 20.
22. Similar to No. 24.
23. Resembles No. 20, but has less drying capacity.
24. Resembles No. 20. Contains *ca.* 1.3 arachidic and lignoceric acids (11). Yields *ca.* 1.5 insoluble bromide (84).
25. Similar to No. 24. "Unsaturated" acids, 91.5–94.5, with iodine value, 103–120 (100).

Class 3. Non-drying Oils: Castor Oil Type

26. Glycerides of hydroxylated fatty acid, not identical with ricinoleic. Liquid fatty acids, consist of equal proportions oleic and linolic (111). Solid fatty acids, *ca.* 10, of which palmitic, 80, and stearic, 20. No linolenic.
27. Largely glycerides of ricinoleic and isoricinoleic acids (79), with small amount saturated acids.
28. Palmitic, stearic, oleic and linolic acids, and hydroxy acids (*ca.* 25), not identical with ricinoleic (5).

Class 4. Animal Oils Largely Glycerides of Oleic Acid

29. Mainly olein, with small amount linolin, palmitin, and stearin. Practically free from volatile fatty acids.
30. Glycerides of oleic with very little solid acids.
31. Resembles No. 30, but contains more saturated glycerides. Stearic 2–3; palmitic, 17–18; oleic, 74.5–76.5; glycerol, 5–10; unsaponifiables, 0.1–0.5 (54).

Class 5. Semi-drying Oils

Glycerides of linolic acid are characteristic constituents

32. Resembles No. 51 (146).
33. Glycerides of oleic and linolic acids. Does not yield insoluble bromide.
34. Glycerides of oleic, linolic and palmitic acids, with small amount of erucic acid (141).
35. Similar to No. 47, but does not give Baudouin reaction (27).

35.5. *v.* (52, 91.5).
37. Glycerides of stearic, palmitic, myristic, lauric, caproic, butyric, and acetic acids; also tiglic and higher homologues of oleic acid, but no oleic (163).
38. Glycerides of oleic and linolic acids.
39. Glycerides of oleic and linolic acids. Slight reaction in Becchi's test and Halphen's test.
40. Olein, linolin, with small amount palmitin and stearin.
41. C, 76.4; H, 11.4; O, 12.2 (163). Glycerides of oleic and linolic acid in approx. proportion 3 to 4.5 (224). Linolic acid, 17–18 (63). Stearic acid present. Fatty acids liberated by hydrolysis in practically same proportion as in original oil (101). Unsaturated acids, 69.7–73.9, with iodine value, 144.2–148 (100).
42. Contains hydnocarpic acid, a cyclic fatty acid of general formula $C_nH_{2n-4}O_2$ (154); with neutralization value, 222.7; specific rotation +67.70°; iodine value, 100 (33). Method of separation from chaulmoogric acid, *v.* (51).

43.5. *v.* (48).
44. Glycerides of oleic, linolic, stearic and myristic acids, with 2.3 lecithin (16). Arachidic acid at least 0.4 (223).
45. Glycerides of oleic, linolic, stearic and palmitic acids.

45.2. *v.* (59.5).
47. C, 75.22; H, 11.13; O, 13.65 (163). Glycerides of oleic, and linolic acids, with small amount stearic, palmitic and myristic acids. Solid fatty acids, 12–14; linolic acid, *ca.* 16 (63). Glycerides of oleic, 48.1; linolic, 36.8; palmitic, 7.7; stearic, 4.6; arachidic, 0.4; unsaponifiables, 1.7. Unsaturated acids, 80.6%, with iodine value, 129.7 (104).
48. Saturated acids, *ca.* 12 (mainly stearic and palmitic); unsaturated, *ca.* 80 (linolic and oleic, with *ca.* 50 of isomer of linolic (109)). Insoluble fatty acids: palmitic, 10; stearic, 2; arachidic, 1; lignoceric, linolenic, linolic and oleic, 88 (199); *cf.* (18).
49. Glycerides of chaulmoogric, hydnocarpic, linolic and myristic acids (45). Chaulmoogric acid: neutralization value, 200–202; specific rotation, +58° to +59°; iodine value, 89.5–90.7 (33). For constants of oils from 8 authentic species of

seeds allied to chaulmoogra, *v.* [147]. Also *v.* references for No. 42.

50. Contains glycerides of oleic and linolic acids.
51. Mainly glycerides of oleic and linolic acids, with small amounts palmitic, stearic, and arachidic acids [195]. Saturated acids, 4.5; olein, 44.8; linolin, 48. 2 [95]. Unsaturated acids, 84.6–86.4, with iodine value, 140.8–142.9 [102].

Class 6. Drying Oils

Usually characterized by linolenic and isolinolenic acids and linolic and isomeric acids

52. Glycerides of oleic (*ca.* 25) and elaeostearic acids (isomer of linolic acid). For constants of oils from different species *v.* [138].
53. Glycerides of α-elaeostearic and oleic acids [[1], p. 207].
54. Glycerides of oleic (56.9), linolic (33.4), stearic, palmitic, myristic and linolenic acids (6.5) [204]. Yields *ca.* 8% insoluble bromide.
55. Glycerides of β-elaeostearic, oleic, and probably linolic acids [144].
56. Oleic, 57; linolic, 33.5; linolenic, 6.5; oxidised glycerides, 2.8 [203].
57. For general characteristics, *v.* [10].
58. Glycerides of linolic, 70; linolenic and isolinolenic, 15; oleic acid, 15 [224].
59. Glycerides of solid fatty acids (palmitic and stearic) *ca.* 10; liquid acids (oleic and linolic) *ca.* 90 [122].
60. For characteristics, *v.* [30].
61. Yields only small amount insoluble bromide [84].
62. Glycerides of oleic acid, 33.4; linolic, 57.5; palmitic, 3.5; stearic, 2.9; arachidic, 0.6; and lignoceric, 0.4 [99].
63. For characteristics, *v.* [29].
64. For characteristics, *v.* [108]. Cross between *J. nigra* and *J. cinere* contains *ca.* 70 linolic acid glycerides, with those of stearic, oleic, and linolenic acids [65].
65. Glycerides of myristic, lauric, oleic, linolic, and linolenic acids. Liquid acids: linolic, 80; linolenic, and isolinolenic, 13; oleic, 7 [224].
66. Elaidin test indicates large proportion olein.
67. C, 78.11; H, 10.96; O, 10.93 [163]. Glycerides of solid fatty acids, 10–15. Liquid acids: oleic, 15–20; linolic, 30; linolenic, 38 [62]. Saturated acids: stearic, 64.4; palmitic, 20 [140]. On bromination, liquid acids yield 20–25 linolenic hexabromide [84]. Yields 2 insoluble mixed glycerides on bromination: (1) linolic-dilinolenic bromoglyceride, 22–25; (2) trilinolic bromoglyceride, or oleic-linolic-linolenic bromoglyceride [182]. Oil contained: α-linolenic acid, 21.1; isomeric linolenic, 2.7; α-linolic, 17.0; hydoxy-acids, 0.5; saturated acids, 8.0; glyceryl radical, 4.1; phytosterol, 1.0; undetermined, 46.2 [55].
69. Glycerides of oleic (20); linolic (65); linolenic acids (5) [224].
70. *v.* Nos. 52, 53, 55.
71. Glycerides of oleic, linolic, linolenic, palmitic and stearic acids. Fatty acids yield 45–51 linolenic hexabromide [66]. Linolenic acid yields hexabromide identical with that from No. 67 [17].
72. Unsaturated acids, 82.8, with iodine value, 157.9 [53].
73–80. For characteristics *v.* [73].
81. *v.* [74, 170].
82. For characteristics *v.* [52].

Class 7. Fish and Marine Animal Oils

Characterized by presence of highly unsaturated glycerides. These oils yield insoluble bromoglycerides, which blacken when heated

83. Glycerides of palmitic, 22.7; myristic, 9.2; stearic, 1.8; unsaturated acids with 18 carbon atoms, 24.9; 20 carbon atoms, 22.2; 22 carbon atoms, 20.2 [190].
84. Glycerides of fatty acids with: C_{14}, 4.5; C_{16} (palmitic), 11.5; palmitoleic, 17; C_{18} (stearic), 2.5; unsaturated (mainly oleic), 36.5; C_{20} (unsaturated), 16; C_{22} (unsaturated), 10; C_{24} (unsaturated), 1.5; unsaponifiables, 1.7 [136]. Oil yields *ca.* 25% insoluble bromoglyceride [84]. Clupanodonic octobromide (8.39%) from fatty acids.
85. Glycerides of highly unsaturated fatty acids (iodine value, 296–317) [40]. Yields clupanodonic octobromide (3.8–6.5%) [183].
86. Glycerides of highly unsaturated acids. Jecoric acid, $C_{18}H_{30}O_2$ (isomeric with linolenic) and palmitic (13.6) [61]. For characteristics of pilchard oil *v.* [119].
87. Glycerides of highly unsaturated acids 13% with iodine value 319.5 [40]. From 13–14 of clupanodonic acid, $C_{18}H_{28}O_2$ (iodine value 344.4) in mixed fatty acids [183]. Glycerides yielded 23.6 insoluble bromide [183].
88. High proportion glycerides of volatile fatty acids [139]. Also esters of other alcohols. Deposits spermaceti. Isopropylacetic acid (Chevreul's "phocoenic" acid) in volatile acids [6].
89. Glycerides of highly unsaturated acids (14.3 with iodine value 285.4) [40]. Valeric acid, 19.9–24 in jaw oil; 2.71 in body oil [139].
90. For characteristics *v.* [180, 181].
91. Glycerides of myristic, palmitic, stearic, oleic, erucic and unsaturated acids $C_{16}H_{30}O_2$ and $C_{20}H_{32}O_2$ [39, 40, 41]. From 17–21 of highly unsaturated acids with iodine value, 324 [189]. Clupanodonic acid present [189]. Acid of general formula $C_nH_{2n-8}O_2$ (clupanodonic acid) isolated. Oil yields *ca.* 34–42 insoluble bromide [84].
92. Glycerides of saturated acids, 17; liquid acids (oleic and physetoleic) 83 [128]; linolic [225]; highly unsaturated acids (iodine value 330), 11.96 [40]. Mixed fatty acids yield 13.9–14 insoluble bromides.
93. Glycerides of highly unsaturated acids (8.57 with iodine value 312.5) [40]. Yields *ca.* 22 insoluble bromide [83]. Oil from certain species contains large proportion of $C_{30}H_{50}$, spinacene [43] and squalene [186]. For characteristics of liver oils (Jap. sharks) *v.* [187, 188]. The liver of *Cetorhinus maximus*, 41.9–55.5 unsaponifiables, mainly squalene.
94. For characteristics *v.* [180]. A shark oil.

Class 8. Insect Oil

95. Glycerides of oleic, linolic (4.38), solid fatty acids (mainly palmitic), phytosterol (not cholesterol); glycerol, 9.42 [185]. Also *v.* [127].

Class 9. Vegetable Fats

96. *v.* [28].
97. *v.* [131].
98. Much stearic, little palmitic acid. Mixed glyceride, oleodistearin, isolated [86, 89].
99. *v.* [179].
100. *v.* [28].
101. *v.* [29].
102. *v.* [28].
103. *v.* [9].
104–106. *v.* [31].
107. *v.* [31, 34].
108. *v.* [31].
109. *v.* [94].
110. *v.* [48].
111. *v.* [31].
112. *v.* [52].
113. *v.* [64, 72]. The crude oil contains *ca.* 3.5% resin, on removal of which a semi-drying oil containing a large amount of linolic acid is obtained. Cong. pt. *ca.* −2°, iodine value, 96.8 [169].

114. *v.* ([145]).
115. Glycerides of oleic acid, 59.6; palmitic, 38.2; and stearic, 1.8; unsaponifiables, 0.2 ([201]).
116. Solid fatty acids, mainly palmitic; liquid acids, oleic ([124]); *v.* ([28]).
117. Glycerides of fatty acids in approximately proportions given: caproic, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 ([57]). For criticisms on method of alcoholysis, *v.* ([59, 174]). Glycerides of kernel oil: caprylic, 9.5; capric, 4.5; lauric, 51; myristic, 18.5; palmitic, 7.5; stearic, 3 (?); oleic, 5; linolic acid glycerides, 1.0 ([13]). Mixed glycerides isolated ([24]).
118. *v.* ([28]).
119. Palmitin, free palmitic acid, olein and small amount linolin ([84]).
120. Glycerides of caproic acid, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 ([58]). *v.* No. 117. Mixed glycerides (5) isolated ([26]).
121–122. *v.* ([28]).
123. Mainly oleo-distearin ([87]); *v.* ([48]).
124. Mainly palmitin, with glycerides of oleic and linolic acids. Stearic acid, 3.3 ([83]).
125. Glycerides of stearic, palmitic and oleic acids. Oleo-distearin and oleo-dipalmitin isolated ([115]). For characteristics of fats from different varieties of pontianak nuts, *v.* ([71]). For relationship of constants, *v.* ([178]).
126. Largely laurin with glycerides of oleic and probably linolic acid; *v.* ([60]).
127–129. *v.* ([192]).
131. Solid acids, 71.4; liquid acid (oleic), 23 ([141]).
132. Glycerides of lauric, myristic and palmitic acids ([121]).
133. *v.* ([28]).
134. *v.* ([126]).
135. Glycerides of myristic, palmitic, stearic, and oleic acids. Glycerol, 13.4 ([1]).
136. Glycerides of myristic acid, 73–74; oleic, 20; butyric, 1; essential oil, 2–3 ([1]).
137. Glycerides of lauric acid, 15.1; myristic, 52.2; palmitic, 0.2; oleic, 3.9. Unsaponifiables, 20.4 ([20]).
138. Glycerides of myristic and oleic acids and an essential oil.
139. *v.* ([28]).
140. *v.* ([72]).
141. *v.* ([196, 200]).
142. *v.* ([197]).
143. *v.* ([126]).
144. Largely palmitic acid and its glycerides. Mixed glyceride isolated ([69]).
145. Insoluble fatty acids, including lauric and arachidic, 91 ([163]). Volatile acids contain butyric and acetic acids. Liquid acids, 55; unsaponifiables, 3.12 ([207]).
146. Glycerides of palmitic and oleic acids. No stearic acid ([83]). Oleo-dipalmitin isolated ([114]).
147. Glycerides of stearic, palmitic, oleic, and linolic acids. Stearic acid in fatty acids, 40 ([83]). Saturated acids, 59.7; oleic, 31.2; other acids, 6.3 ([63]). Mixed glycerides ([113, 116]). Oleic, 43–45; palmitic, 23–25; stearic, 31–33. Five mixed glycerides isolated ([3]).

149. *Ca.* 75 solid (palmitic) and 25 liquid acids (oleic) ([121]).

Class 10. Animal Fats

150. Mainly glycerides of palmitic, stearic and oleic acids, with small amounts linolic. Palmito-distearin and stearo-dipalmitin isolated ([23]). Stearic acid, 7–13 ([83]).
151. Mainly glycerides of palmitic, stearic, and oleic acids, with traces of linolic and linolenic acids ([63]). Mixed glycerides isolated include oleo-dipalmitin, stearo-dipalmitin, oleo-palmito-stearin and palmito-distearin ([23]). These crystallize in different form from lard glycerides.
152. Glycerides of palmitic, stearic and oleic acids. Stearic, 0–36 ([83]).
153. Mainly triolein, with small amounts stearo-dipalmitin, palmito-diolein, and oleo-dipalmitin ([4]). Fatty acids contain stearic, 3.8; palmitic, 21.2; and oleic, 72.3 ([25.5]).
154. For characteristics, *v.* ([117]).
155. Glycerides of palmitic, stearic and oleic acids.
156. Glycerides of oleic and linolic acids, 9.9 ([63]). Stearic acid sometimes present ([1]). No linolenic ([63]).
159. *v.* Nos. 151, 152.
160. Glycerides of stearic acid, 19–21; palmitic, 20–21; oleic, 53–59; glycerol, 5–10; unsaponifiables, *ca.* 0.5 ([54]).
161. Glycerides of butyric, caproic, caprylic, and capric acids, 8.35; oleic, 32.5; stearic, 1.83; palmitic, 38.61; myristic, 9.89; and lauric, 2.59, with 1.83 dihydroxystearic acid ([35]). Stearic acid, 0–22 ([137]). Mixed glycerides include butyro-diolein, butyro-palmito-olein and oleo-dipalmitin ([2]). For particulars of *ghee*, *v.* ([29.1, 29.2, 109.5, 193.5]).

Class 11. Liquid Animal Waxes

162. Mainly various alcohols (iodine value, 64.8–65.2) in combination with fatty acids of oleic series ([1]).
163. Mainly alcohols, chiefly of ethylene series, in combination with fatty acids of oleic series. Iodine value of alcohols, 63.9–74.1 ([22]).

Class 12. Vegetable Non-glyceridic Waxes

164. Contains a hydrocarbon (M. P. 59°), an alcohol, $C_{17}H_{36}O$; myricyl alcohol, carnaubic acid, cerotic acid, and a hydroxy acid ([175]).
165. From 50–52 hydrocarbons ([37]).
166. Esters of montanic acid and unsaponifiable matter ([157, 162, 212]).

Class 13. Animal Non-glyceridic Waxes

167. Complex mixture of esters of higher alcohols; also glycerides ([50, 112, 165]).
168. Free cerotic acid and esters of alcohols ([36]).
169. Free cerotic acid, myricin, with smaller amounts free melissic acid, unsaturated fatty acids, and ceryl and other alcohols ([81, 96]). Free hydrocarbons, 11.0–17.5 ([38]).
170. *v.* ([36]).
171. Chiefly ceryl cerotate with small amounts of other esters.
172. Mainly cetin or cetyl palmitate with very small amounts of similar esters or glycerides.

4. POLENSKE VALUES

General index No.	Polenske value	General index No.	Polenske value
148	0.12	133	7.0
134	0.25	120	9–10
36	0.3	116	9–12
81	0.4	102	10.2
104	0.5–0.65	96	10.2–12.6
161	1.5–3.0	103	15.6
154	4.9–8.7	117	16.8–17.8
100	5.9		

5. COMPRESSIBILITY

1 megabarye^{-1} = 10^{-6} cm^2 dyne^{-1} = 1.0133A_n^{-1} = 0.0690 in.^{2} lb.$^{-1}$ = 0.9807 cm^2 kg^{-1}.

t = 14.8°C. ΔP = 1 to 10 atm ([134])

General index No.	27	67	13	91	8
$\frac{10^6}{V}\frac{\Delta V}{\Delta P}$ =	47	52	53	53	56

5. COMPRESSIBILITY.—(*Continued*)

$t = 40°$. d = density, g cm^{-3}. $C = \frac{10^6}{V}\frac{dV}{dP}$ per megabarye (96)

P, kg cm^{-2}	General index No. 27		General index No. 20		General index No. 163	
	Castor oil		Rape oil		Sperm oil	
	d	C	d	C	d	C
0	0.9414		0.8980		0.8660	
157.5	0.9488	50.5	0.9058	55.7	0.8746	60.8
315.0	0.9558	48.6	0.9129	52.1	0.8820	58.2
472.5	0.9625	47.0	0.9199	51.1	0.8898	56.3
630.0	0.9686	45.3	0.9270	50.5	0.8958	53.4
787.5	0.9748	44.5	0.9330	48.2	0.9124	51.5
945.0	0.9808	43.2	0.9381	46.0	0.9088	50.5
1102.5	0.9858	41.5	0.9440	44.8	0.9136	48.1
1260.0	0.9906	40.1	0.9496	43.6	0.9196	46.9
1417.5	0.9958	39.4	0.9547	42.7	0.9249	45.7
1575.0	1.0010	38.3				

6. VISCOSITY

Conversion factors for different viscometer degrees, *v.* vol. I, p. 32.

Change of viscosity of oils with temperature (91).

Fish oils (205).

Solutions of camphor, of ethyl alcohol and of chloroform in olive oil (35.5).

Lubricating oils (12).

η in Poises

OILS (12, 171)

t = 60°F = 15.5°C

General index No.	$\eta_{15.5}$	General index No.	$\eta_{15.5}$
163	0.42–0.44	26	0.858–0.878
At 100°F	0.185	13	0.860
At 150°F	0.085	1	0.869
At 212°F	0.046	21	0.935
67	0.55	3	0.942–0.950
58	0.697	8	0.950–1.01
61	0.697	At 100°F	0.377
84	0.711	At 150°F	0.154
92	0.724	At 212°F	0.070
62	0.776	31	0.987–1.13
69	0.789	20	1.08–1.18
51	0.789	At 100°F	0.42–0.45
47	0.797	At 150°F	0.18–0.19
48	0.797	At 212°F	0.08–0.09
14	0.857	27	*v. infra*
41	0.82–0.994		

FATS (12, 171)

t = 50°C

General index No.	η_{50}	General index No.	η_{50}
117	0.154	150	0.258
120	0.171	159	0.274
147	0.171	167	
105	0.175	At 150°F	1.672
119	0.198	At 212°F	0.314
160	0.256		

Kinematic Viscosity

R = Redwood; degrees at 70°F = sec per 50 cc. $\eta_{70} = (0.0026R - 1.715/R) \times d$ (±5% approx.)

General index No.	$R_{70°F}$ *cf.* (48)	General index No.	$R_{70°F}$ *cf.* (48)
167	212	29	
84	188	At 60°F	356– 534
At 120°	71.3	52	853–1433
65	232	At 60°F	1230–2178
69	255–259	57	
59	249–294	At 100°F	1160–1190
61	263–292	117	
57	269–272	At 140°F	63.9
8	312	123	
3	350	At 140°F	101.1
22	371	106–104	
23	385	At 140°F	110.4
20	372–465	149	
24	402	At 140°F	104.0
25	425		

DENSITY AND VISCOSITY OF CASTOR OIL (No. 27) (12, 105)

t, °C	d, g cm^{-3}	η, poises	t, °C	d, g cm^{-3}	η, poises
5	0.9707	37.60	25	0.9569	6.51
6	.9700	34.475	26	.9562	6.04
7	.9693	31.56	27	.9555	5.61
8	.9686	28.90	28	.9548	5.21
9	.9679	26.45	29	.9541	4.85
10	.9672	24.18	30	.9534	4.51
11	.9665	22.075	31	.9527	4.21
12	.9659	20.075	32	.9520	3.94
13	.9652	18.25	33	.9513	3.65
14	.9645	16.61	34	.9506	3.40
15	.9638	15.14	35	.9499	3.16
16	.9631	13.805	36	.9492	2.94
17	.9624	12.65	37	.9485	2.74
18	.9617	11.625	38	.9478	2.58
19	.9610	10.71	39	.9471	2.44
20	.9603	9.86	40	.9464	2.31
21	.9596	9.06	37.8	.9473	2.729
22	.9589	8.34	65.6	.9284	0.605
23	.9583	7.67	100.0	.9050	0.169
24	.9576	7.06			

7. VISCOSITY UNDER PRESSURE

VALUES OF η_P/η_0 AT 40°C (98)

P kg cm^{-2}	General index No. 20 Rape oil	General index No. 163 Sperm oil	P kg cm^{-2}	General index No. 27 Castor oil
0	1.00	1.00	0	1.00
157.5	1.125	1.23	23.94	1.03
315.0	1.44	1.535	227.6	1.365
472.5	1.875	1.94	550.5	2.295
630.0	2.345	2.39	864.6	3.625
787.5	3.905		1164.0	5.255
866.2		3.135		
945.0	3.495			
1102.5	4.21	4.02		
1260.0			(*v. also* Fig. 1.)	

Influence of Temperature on Viscosity under Pressure

400 kg cm^{-2} (6000 lb. in.$^{-2}$) produces approx. the following % increase in viscosity: Lard (No. 150) 75% at 25°, 34% at 100°; sperm (No. 163) 72% at 25°, 29% at 100°.

For lard oil (No. 150) the solidifying pressure at 21° is *ca.* 155 kg cm^{-2} (22 800 lb. in.$^{-2}$) and at 100° the viscosity is increased 240% by 1500 kg cm^{-2} and 600% by 3000 kg cm^{-2} (44 000 lb. in.$^{-2}$) [*Report of Research Sub-committee on Lubrication, Amer. Soc. Mechan. Engineers*, No. **1833** (Dec. 1921)].

8. MELTING POINT

General index No.	M. P., °C	General index No.	M. P., °C	General index No.	M. P., °C
4	16	117	20–28	148	32
11	22.4	118	29	149	37.5–42
20	−2 to −6	119	27–43	150	29.8–45.5
23	−4	120	23–30	151	42–50
32	*ca.* 8	121	30–30.5	152	47–49
52	Below −17	122	30.2–31	153	27.5–32.5
54	Below −18	123	41–42	155	48–54
65	−12 to −28	124	29–33	156	18–39
96	24.9 (pulp)	125	28–31	157	33–40
	19.4–24 (kernel)	126	32–36	158	35–46
97	38–39	130	10–24	159	41–51
98	40–41	131	35–40	160	44–45
100	35 (pulp)	132	38–42	161	28–36
	30.6–32.5 (kernel)	133	27–28.5	164	83–91
101	22–24	135	40–48	165	68–70
102	26.1	136	38–51	166	76
103	23.6	137	37.8		95–97*
105	23–29	138	39–43	167	39–42
106	42	140	26.5–27	168	65–66
107	28–31	141	4–18	169	62–66
109	25–35	142	32	170	62–66
110	32	144	53–56	171	81–83
111	37–42	145	22–28	172	42–49
113	37	146	36–46		
114	15–30	147	26.6–34.5		
116	29.5–35.5				

* Montan wax.

Under Pressure No. 172 [49]

P., atm.	M. P., °C	P., atm.	M. P., °C	P., atm.	M. P., °C
1	46.5	56	49.36	141	50.90
11	48.33	96	50.10	182	51.38
20	48.64				

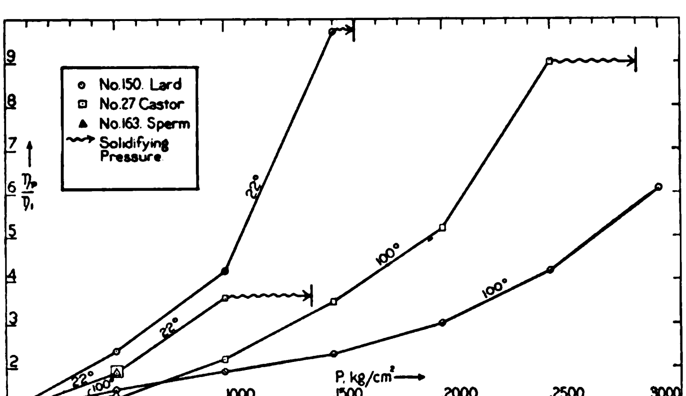

FIG. 1.—Effect of pressure on relative viscosity of oils.

9. BOILING POINT OF OILS

No. 27, castor, *ca.* 265°C. No. 67, linseed, *ca.* 287°C. B. P. varies with time owing to decomposition.

10. THERMAL EXPANSION

The value of $d^t_{15.5}$ for any oil for temperatures between 10° and 25° may be approximately calculated from the expression $d^t_{15.5} = d^0_{15.5}(1 - 0.0007\,t) = (\text{approx.})d^{15.5}_{15.5} - 0.0006_6(t - 15)$ [210].

Values of $\dfrac{d^{t_1}_{15.5} - d^{t_2}_{15.5}}{t_2 - t_1} \times 1000$. $t_2 = 98°$ or $99°$ [1]

Values uncorrected for expansion of glass plummet of Westphal balance

General index No.	$t_1°$	Difference for 1°C	General index No.	$t_1°$	Difference for 1°C
117	40	642	159	50	673
119	50	717	161	40	617
120	40	657	164	90	97_5
144	60	692	169	80	75_0
147	50	717	172	60	716
150	40	650			

Correction in Density, $d^{15.5}_{15.5}$, for 1°C

$$A = -10^3 \frac{dd}{dt} \text{ at } 15°C$$

General index No.	A	General index No.	A	General index No.	A
3	0.655	41	0.629	84	0.722
8	.629	47	.624	89	.654
20	.620	61	.637	92	.615
27	.653	67	.648	93	.646
29	.658	83	.654	161	.643
31	.625	84	.697	162	.648

Empirical Equations

$$V_t = V_0(1 + a \times 10^{-6}t + b \times 10^{-6}t^2 + c \times 10^{-9}t^3)$$

General index No.	Name	a	b	c	Range	Lit.
169	Beeswax.....	738_6	1.75_2	−8.27	0–100	[132]
8	Olive oil......	708	-0.77_3	8.27	9–106	[214]
8	Olive oil......	682_{15}	1.140_{53}	5.39		[215]
8	Olive oil......	$d^{20}_4 = 0.91268$, $d^{30}_4 = 0.90590$				[216]

11. SPECIFIC HEAT

Mean c_p between 20° and 30°. 1 joule g^{-1}/°C = 0.2389 cal_{15} g^{-1}/°C or BTU_{60} $lb.^{-1}$/°F [130].

General index No.....	8	12	20	26	31
c_p, joules g^{-1}/°C......	1.98_8	2.05_1	1.96_3	2.08_4	1.91_3

General index No.............	40	47	52, 53	67
c_p, joules g^{-1}/°C..............	1.98_4	2.00_0	1.83_3	1.84_6

General index No..........	91	117	150	163	169 [221]
c_p, joules g^{-1}/°C...........	1.89_1	2.13_9	2.02_1	1.93_8	2.0

For thermal conductivity of beeswax *v.* p. 311.

12. HEAT OF COMBUSTION

H_v = heat of combustion, at constant volume, in kilojoules per gram. 1 kj g^{-1} = 238.9 cal_{15} g^{-1} = 430.1 BTU_{60} $lb.^{-1}$

General index No.	Oil	Iodine value	Free acids as oleic	H_v [166]
3	Arachis.................	105.9	0.16	39.39
8	Olive....................	85.1	2.51	39.58
13	Almond.................	98.1	5.13	39.56
20	Rape.....................	107.4	0.82	39.71
27	Castor...................	84.1	0.26	37.09
47	Sesame..................	105.3	1.65	39.32
51	Maize....................	120.3	3.32	39.39
51	Maize (crude)...........	122.4	1.68	39.42
67	Linseed (fresh)..........	182.4	4.30	39.19

General index No.	Oil	Iodine value	Free acids as oleic	H_v (166)
69	Poppy	129.6	2.66	39.26
83	Menhaden		0.36	39.17
84	Whale			39.64
91	Cod liver	165.6	0.56	39.49
93	Shark			39.22
150	Lard	74.3	0.74	39.55
163	Sperm	78.7	0.78	41.62

General index No.	Fat	H_v	Lit.
150	Lard	39.77–40.40	
	Oleomargarine	40.18	
161	Butter fat	39.00–39.18 38.47–38.63	(173)
153	Goose fat	39.77	(173)
172	Spermaceti	41.62	(166)

$H_v \times d_{15}^{15} = 36–37$. For H_v of fatty acids *v.* (173).

13. FLASH POINTS OF OILS AND FATS

See also (12, 158)

1. Closed Test (42)

General index No.	Oil or fat	Average value °F	Average value °C	Extreme values, °F
8	Olive	437.5	225.2	410–465
162	Arctic sperm	446.2	230	390–485
163	Southern sperm	457.5	236.3	420–485
20	Rape, Black Sea refined	464.4	240.2	430–490
31	Neat's foot	470.3	243.5	410–540
84	White whale	476.0	246.4	430–530
20	Rape oil, E. Indian refined	478.6	248.1	410–510
41	Cottonseed	523.0	272.7	500–540

2. Methods Not Stated (8)

General index No.	Oil or fat	Flash point °F	Flash point °C	Fire point °F	Fire point °C
67	Linseed	378	192	572	300
67	Linseed, boiled	419	215	468	242
150	Lard, No. 2	419	215	468	242
163	Sperm, No. 1	428	220	518	270
31	Neat's foot	439	226	523	273
8	Olive	451	233	541	283
27	Castor	459	237		
51	Maize (corn)	480	249	635	237
163	Sperm, No. 2	486	252	574	302
150	Prime lard	530	277	644	340
41	Cottonseed	582	305.6	644	340

14. ELECTRICAL CONDUCTIVITY

$\kappa = A \times 10^{-5}$ mhos (*cf.* vol. 1, p. 35) (90)

General index No.		A ($= \kappa \times 10^5$) at 18°C
161	Butter	646–701
	Margarine	822–863
41	Cottonseed oil	863
3	Arachis oil	872
47	Sesame oil	878
8	Olive oil	993

Relative Values on an Arbitrary Scale (15)

Oils

General index No.	8	8	47	69	21	1
°C	Olive I	Olive II	Sesame	Poppy	Ravison rape	Peach kernel
0	0.00	0.00	0.2	0.48	7.9	42
20	0.00	0.00	0.9	3.2	19.4	132
40	0.00	0.06	1.7	7.0	45	252
60	0.00	0.14	2.3	17.0	108	501
80	0.00	0.70	8.6	34.9	168	102$_4$
100	0.00		18.0	60.5	236	174$_8$
120	0.01		28.8	115	340	297$_4$
140	0.06		47.0	218	480	440$_0$
160	0.51		107		670	623$_0$
180	1.62	7.62	182.$_5$		100$_0$	870$_0$
200	3.38	10.7	275		145$_0$	1160$_0$
220	6.08	15.0	400		203$_0$	1470$_0$
240	10.4	21.6	660		284$_0$	182$_{80}$
260	16.5	33.0	120$_0$		400$_0$	222$_{50}$
280	23.7	52.5	227$_0$		600$_0$	277$_{50}$
300	31.7$_0$	83.0				

Drying oils heated in contact with air acquire greater conductivity; also oils that have become rancid. If a definite temperature has not been reached (about 260°) the original conductivity is restored on cooling. Of the oils tested, linseed oil showed the greatest conductivity.

	Fats				Waxes			
General index No.	157	150	88	117	172	169	164	144
°C	Chicken fat	Lard	Dolphin oil	Coconut oil	Spermaceti	Beeswax (yellow)	Carnauba wax	Japan wax
0	1.7				0.0	0.0	14.5	0.0
20	2.2 (liquid)	6.6	5.8 (liquid)	0.48	0.02	0.10	28.0	0.0
40	3.3	8.8 (liquid)	9.4	1.25 (liquid)	1.3 (liquid)	1.0	55.6	0.0
60	5.3	18.5	14.8	5.02	2.9	7.1	85.5	0.0 (liquid)
80	7.8	24.0	30.9	7.80		29.0 (liquid)	100	19.0
100	11.0	28.5	58.0	14.0	4.5	36.0	175	27
120	14.1	38.0	87.5	22.4	8.6	64.0	316	50
140	17.6	61	157.4	33.7	13.6	121	520	90
160	21.5	101	280.0	48.0	19.0	260	109$_0$	155
180	25.4	126	369	102	24.2	600		236
200	30.0	60	470		30.8			343
220	35.1	60.5	625					641
240	40.5	99	880					
260	46.8	158						
280	54.0	230						
300	63.5	339						

15. DIELECTRIC CONSTANTS

Mixtures of Castor Oil (No. 27) and Toluene (167, 107, 193); *cf.* (7)

Per cent castor oil	0	10	20	30	40
ϵ at 12.5°	2.655	2.820	3.102	3.264	3.452
ϵ at 20.0°	2.541	2.748	2.920	3.150	3.352
$-\frac{\Delta\epsilon}{\Delta t}$	0.0141	0.0158	0.0174	0.0190	0.0206

Per cent castor oil	50	60	70	80	90	100
ϵ at 12.5°	3.746	3.952	4.152	4.308	4.564	4.798
ϵ at 20.0°	3.536	3.684	3.950	4.182	4.334	4.578
$-\frac{\Delta\epsilon}{\Delta t}$	0.0223	0.0239	0.0255	0.0272	0.0288	0.0304

For castor, olive, and linseed oils *see* (222).

16. REFRACTIVE INDEX AND BUTYROREFRACTOMETER READING

In preparing Table 16*B* below, butyrorefractometer values have first been converted into values of n_D by means of the *conversion factors* given in Table 16*A*. Values of n_D below 25° and above 40°C have then been converted to 25° and 40°, respectively, by means of the convenient approximate relation,

$$\frac{\Delta n_D}{\Delta t} = -0.00037\ (^{106}).$$

16*A*. Table for Converting Butyrorefractometer Readings into Refractive Indices

Scale divisions	n_D	Scale divisions	n_D	Scale divisions	n_D	Scale divisions	n_D
0.0	1.4220	19.5	1.4373	45.2	1.4560	72.7	1.4740
0.5	1.4224	20.0	1.4377	46.0	1.4566	73.5	1.4745
1.0	1.4228	20.4	1.4380	46.6	1.4570	74.3	1.4750
1.2	1.4230	21.1	1.4385	47.3	1.4575	75.1	1.4755
1.5	1.4232	21.7	1.4390	48.0	1.4580	76.0	1.4760
2.0	1.4236	22.5	1.4396	48.8	1.4585	76.8	1.4765
2.5	1.4240	23.0	1.4400	49.5	1.4590	77.7	1.4770
3.0	1.4244	23.5	1.4404	50.2	1.4595	78.6	1.4775
3.5	1.4248	24.3	1.4410	51.0	1.4600	79.4	1.4780
3.7	1.4250	25.0	1.4415	51.7	1.4607	80.3	1.4785
4.0	1.4254	25.6	1.4420	52.5	1.4610	81.2	1.4790
4.5	1.4256	26.3	1.4425	53.3	1.4615	82.0	1.4795
5.0	1.4260	27.0	1.4430	54.0	1.4620	82.9	1.4800
5.5	1.4264	28.3	1.4440	54.8	1.4625	83.8	1.4805
6.0	1.4268	29.0	1.4445	55.6	1.4630	84.6	1.4810
6.2	1.4270	29.7	1.4450	56.3	1.4635	85.5	1.4815
7.0	1.4276	30.0	1.4452	57.1	1.4640	86.4	1.4820
7.5	1.4280	31.0	1.4460	57.9	1.4645	87.3	1.4825
8.0	1.4284	31.8	1.4465	58.6	1.4650	88.2	1.4830
8.7	1.4290	32.5	1.4470	59.4	1.4655	89.1	1.4835
9.0	1.4292	33.0	1.4474	60.2	1.4660	90.0	1.4840
9.5	1.4296	33.9	1.4480	60.9	1.4665	90.9	1.4845
10.0	1.4300	34.6	1.4485	61.7	1.4670	91.8	1.4850
10.5	1.4304	35.3	1.4490	62.5	1.4675	92.7	1.4855
11.0	1.4308	36.0	1.4495	63.2	1.4680	93.6	1.4860
11.3	1.4310	36.7	1.4500	64.0	1.4685	94.0	1.4862
12.0	1.4316	38.1	1.4510	64.8	1.4690	94.5	1.4865
12.5	1.4320	38.7	1.4515	65.6	1.4695	95.4	1.4870
13.8	1.4330	39.5	1.4520	66.4	1.4700	96.0	1.4873
15.0	1.4340	40.0	1.4524	67.2	1.4705	96.3	1.4875
15.5	1.4343	40.9	1.4530	68.0	1.4710	97.2	1.4880
16.4	1.4350	41.5	1.4535	68.7	1.4715	98.1	1.4885
17.0	1.4354	42.3	1.4540	69.5	1.4720	99.1	1.4890
17.8	1.4360	43.0	1.4545	70.3	1.4725	100.0	1.4895
18.5	1.4366	43.7	1.4550	71.1	1.4730		
19.1	1.4370	44.4	1.4555	71.9	1.4735		

For more extensive data *v.* (106). For specific refraction (Lorenz) *v.* (156).

The following empirical relations have been proposed:

$$\frac{n^2 - 1}{n^2 + 2} \times \frac{100}{d_4^t} = 33.07 + 0.00075(I) - 0.01375\ (S) + 0.002(t - 15)$$

where d = density, S = saponification value, and I = iodine value, all at t°C. When hydroxy acids are present, the first constant of the equation is lower (14).

$$n_D^{40} = 1.4643 - 0.000046\ (S) - 0.0096\left(\frac{A}{S}\right) + 0.0001171\ (I),$$

where A = acid value.

An observed refractive index higher than that calculated from this formula indicates oxidation of the oil (149).

In the case of hydrogenated cottonseed, linseed, arachis, sesame and sardine oils, and bassia tallow,

$$n_D^{60} = [1.4468 + 1.03 \times 10^{-4}\ (I) + 7.3 \times 10^{-3}(I^2)] \pm 0.0005.$$

The refractive indices of hydrogenated castor oil are lower than those of other oils with similar iodine values, owing to reduction of the hydroxyl groups by the catalyst (178).

16*B*. Refractive Indices

Finding No.	General index No.	n_D^{25}	n_D^{40}
1	117	1.453	1.4477–95
2	127	1.4543	
3	101		1.4490–6
4	132		1.4499
5	118		1.4496–505
6	100		1.4497–506
7	103		1.4503
8	135		1.4511
9	133		1.4512
10	96		1.4502–25
11	162	1.4567–71	1.4511–5
12	120		1.4492–543
13	146		1.4470–579
14	154		1.4499–551
15	161*		1.4528
16	163	1.4573	1.4488–581
17	98		1.4540
18	168–170		1.4538–66
19	99		1.4521–85
20	104		1.4552–656
21	147		1.4537–80
22	97	1.4605	
23	125		1.4559–66
24	150	1.4609–20	1.4542–81
25	142	1.4617	1.4559–66
26	88†	1.4517–717	
27	161‡		1.4534–89
28	152		1.4545–85
29	123	1.4628	1.4566
30	161		1.4555–78
31	116		1.4567
32	89	1.4622–5	1.4568
33	165		1.4569
34	144		1.4560–91
35	149		1.4575
36	157		1.4580
37	11	1.4535–633	1.4581
38	15	1.4635	
39	99		1.4521–85
40	138		1.4588–600
41	105		1.4578–614
42	145		1.4597
43	4		1.4593–613
43.1	131		1.4593–624
44	153		1.4583–626
45	29		1.4607
46	105		1.4605–13
47	31	1.4643–85	
48	139		1.4610
48.5	16.7	1.4664	
49	88	1.4665	
50	107		1.4609–16
51	134		1.4607–20

* Indian cow.
† Japanese.
‡ Indian buffalo.

16*B*. Refractive Indices.—(*Continued*)

Finding No.	General index No.	n_D^{25}	n_D^{40}
52	5	1.4667	
53	108		1.4584–649
54	17	1.4662–89	
55	17		1.4618
56	33	1.4671	
57	12	1.4672	
58	13		1.4593–646
59	119		1.4603–39
60	7		1.4593–652
61	2		1.4623
62	112	1.4678	1.4623
63	8	1.4657–67	1.4603–56
64	39		1.4602–57
65	9	1.4682–8	
66	3		1.4620–53
67	26	1.4681–91	1.4636
68	16	1.4679–702	
69	1	1.4682–701	1.4630–49
70	14	1.4636–705	1.4635–49
70.5	35.5		1.4641
71	23	1.4640–6	1.4642
72	76	1.4698	1.4643
73	40	1.4698	
74	141		1.4637–54
75	24		1.4649
76	87		1.4633–66
77	6	1.4705	
78	19	1.4710	1.4650
79	124	1.4700–25*	1.4646–54
80	22		1.4653
81	111		1.4642–64
81.5	16.5		1.4654
82	20		1.4649–59
83	35		1.4656
84	156	1.4658–702	1.4618–96
85	10	1.4711	
86	51	1.4733	1.4656–62
86.5	43.5		1.4660
87	47	1.4704–17†	1.4649–75
88	25	1.4718	
89	28	1.4713–25	1.4659–78
90	68	1.4724	1.4671–8
91	57		1.4675
92	94	1.4730	1.4675
93	63		1.4666–85
94	21	1.4710–74	
95	38	1.4724–39	
96	48	1.4723–56	1.4675–82
97	44	1.4715–36	1.4679
98	79		1.4678–85
99	95	1.4731–43	
100	50	1.4751	
101	73	1.4756	
102	59	1.4769	1.4679–91
103	84	1.4679–724	1.4659–713
104	164		1.4672–701
105	80		1.4685
105.5	56.5		1.4688
106	69	1.4739–42	1.4679–98
107	34	1.4743	
108	62		1.4659–721

* U. S. A. Standard. † U. S. A. limits.

Finding No.	General index No.	n_D^{25}	n_D^{40}
109	92	1.4742–62	1.4685–702
110	27	1.4771	1.4659–730
111	54, 56	1.4760–90	1.4696
112	85		1.4665–729
113	65	1.4770	1.4690–710
114	32		1.4701
115	37		1.4710
116	74		1.4710
117	137		1.4710
118	91	1.4758–83	1.4702–35
119	94.5	1.4701–852	
121	93	1.4825	1.4685–770
122	42	1.4775–91	1.4721–39
123	83	1.4787	1.4731–6
124	126	1.4783	1.4735
125	68.5		1.474
126	58		1.4740–5
127	67	1.4807–15*	1.4739–48
128	67	1.4797–802†	
130	49	1.4777–9	1.4720–74
131	143	1.4770	1.4723–72
132	113		1.4737–60
133	71		1.4753
134	86	1.4763–852	
135	82	1.4818	1.4768–72
137	45.3	1.474	
138	45.5	1.475	
140	42.2	1.4750	
141	167		1.4784–822
142	42.2	1.4778	
143	41.5	1.4780	
144	42.4	1.4780	
145	42.3	1.4786	
146	78		1.4861
147	81	1.4857	
148	60	1.4953	
149	52, 53, 55	1.515–20‡	1.5080–128
150	70	1.5099–186	

* Russian.
† American.
‡ Am. Soc. Testing Materials limits.

16*C*. Optical Dispersion

$$\omega = \frac{n_F - n_C}{n_D - 1}$$

Fryer and Weston (67) at 40°

General index No.	n_D	$n_F - n_C$	$1/\omega$
1	1.46439	0.00910	51.0
3	1.46431	0.00878	52.9
8	1.46184	0.00862	53.6
13	1.46403	0.00890	52.1
20	1.46770	0.00936	50.0
27	1.47194	0.00897	52.7
41	1.46535	0.00910	51.1
47	1.46650	0.00908	51.3
51	1.46711	0.00938	49.8
52	1.51256	0.01904	26.9
58	1.47404	0.00980	48.4
61	1.46968	0.00935	50.2
62	1.47211	0.00973	48.5
65	1.47054	0.00985	47.8
67	1.47379	0.01032	45.8

16C. Optical Dispersion.—(*Continued*)

General index No.	n_D	$n_F - n_C$	$1/\omega$
69	1.46984	0.00978	48.0
71	1.47527	0.00984	48.3
83	1.47361	0.00979	48.4
84	1.46630	0.00918	50.8
92	1.47018	0.00918	50.8
93	1.46849	0.00955	49.0
117	1.44924	0.00751	59.8
120	1.45034	0.00812	55.4
147	1.45724	0.00853	53.6
150	1.45928	0.00851	53.8
161	1.45427	0.00830	54.7
163	1.45814	0.00864	53.0
172	1.44066*	0.00740	59.5
Szalagyi (177) at 45°			
3	1.46444	0.00949	48.9
8	1.46040	0.00877	52.5
20	1.46553	0.00933	49.9
27	1.47027	0.00904	52.0
41	1.46394	0.00917	48.7
47	1.46398	0.00917	50.6
58	1.46889	0.00962	48.7
67	1.47224	0.01018	45.1
91	1.46984	0.00988	47.5
117	1.44746	0.00739	60.5
150	1.45716	0.00818	55.9
150	1.45753	0.00882	51.9
161	1.45213	0.00830	54.4
161	1.45296	0.00784	57.6

* At 56°.

(93) describes a method based on the inversion of the spectrum colors shown by tung oil.

17. OPTICAL ROTATION OF OILS

Values expressed in reading on Laurent's saccharimeter (200 mm at 20°) unless otherwise stated (148)

General index No.	Oil or fat	Optical rotation
69	Poppy oil....................	0.0
3	Arachis oil....................	−0.1 to −0.4
14	Apricot kernel oil.............	−0.2
65	Walnut oil....................	−0.3
13	Almond oil....................	−0.7
20	Rape oil......................	−1.6 to −2.1
82	Stillingia oil.................	−18.6
8	Olive oil......................	+0.2 to +0.6
47	Sesame oil....................	+0.8 to +2.4
27	Castor oil.....................	+7.6 to +9
37	Croton oil....................	+14.5 to +16.4
42	Hydnocarpus oil α_D^{20}..........	+49.50 to +51.5
49	Chaulmoogra oil α_D^{20}..........	+50.8 to +58.2

PROPERTY-SUBSTANCE TABLES

The bold-faced numbers are intervals on the scale of property values. The other numbers are General Index Numbers in the order of the value of the property.

18. DENSITY

Oils.—15/15: **0.861**: 163, 162, 6, 88, 94.5. **0.91**: 88, and all others except 60. **0.95**: 49, 27, 60, 42.2. **0.97.**

Fats.—100/15.5: **0.852**: 148, 138, 141, 149, 125, 116, 119, 147, 131, 108, 115, 109, 111, 99, 130, 146, 117. **0.86**: 141, 146, 117, and all others except 155. **0.90**: 155. **0.91.**

Waxes.—100/15.5: **0.805**: 172, 171, 169, 167, 164. **0.85.**

19. MELTING POINT

Fats.—**4°**: 141. **10°**: 141, 130, 114, 156, 96. **20°**: 130, 114, 156, 117, 145, 101, 103, 105, 120, 96. **25°**: 114, 156, 117, 145, 105, 120, 109, 102, 140, 147, 119, 133, 153, 125, 107, 161, 100, 118, 116, 124, 150. **30°**: 156, 109, 147, 119, 153, 125, 107, 161, 116, 124, 150, 121, 148, 142, 126, 110, 157. **35°**: 156, 119, 161, 116, 150, 126, 157, 158, 131, 146, 113, 111, 149, 137, 97, 132, 136, 167, 138. **40°**: 119, 150, 158, 146, 111, 149, 132, 136, 167, 138, 98, 135, 123, 159, 106, 172, 151, 160. **45°**: 150, 158, 146, 136, 135, 159, 172, 151, 152, 155, 144. **50°**: 136, 159, 155, 144. **60°**: 169, 170, 168, 165. **70°**: 166. **80°**: 171, 164. **90°**: 166, 164.

20. CONGELATION TEMPERATURE

Oils.—**−30°**: 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13. **−20°**: 51, 65, 58, 77, 13, 81, 54, 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13, 81, 54, 52, 53, 15, 74, 14, 1, 45, 34, 69, 5, 27, 37, 28, 75, 40, 25, 68, 62, 24, 88, 38. **−15°**: 51, 65, 77, 13, 14, 45, 27, 37, 28, 48, 23, 43, 41, 61, 64, 17. **−10°**: 37, 39, 12, 16, 10, 46, 20, 21, 3, 36, 8. **−5°**: 20, 3, 8, 47, 83, 99, 91, 84, 29, 31, 30, 92, 82. **0°**: 41, 99, 29, 31, 53, 30, 7, 95, 33, 26, 6. **5°**: 41, 31, 30, 4, 45.3. **10°**: 41, 30, 4, 11, 42.4, 42.5. **20°**: 30, 42.3, 42.2, 42.1, 41.5. **75°.**

21. ACETYL VALUE

0: 91, 161, 117, 172, 150, 147, 3. **3**: 3, 5, 163, 13. **5**: 163, 13, 51, 116, 26, 120, 58, 31, 159, 54. **10**: 51, 26, 54, 8, 65, 125, 84, 44, 69, 160, 36, 20, 41, 28. **15**: 26, 84, 37.5, 44, 41, 169, 92, 119, 59, 153, 28, 144, 37. **20**: 26, 84, 44, 41, 144, 68, 141, 63, 82, 28. **30**: 141, 37, 28, 113. **40**: 28, 2. **50**: 164. **55. 149**: 27. **150.**

22. IODINE VALUE

Oils.—**50**: 11, 30, 31, 4. **60**: 30, 31, 4, 29, 42.5. **70**: 31, 29, 16.5, 6, 5.5, 39, 2, 8, 45.3. **80**: 16.5, 39, 8, 42.1, 18, 12, 27, 42, 5, 9, 3, 42.2. **90**: 42.3, 39, 42, 3, 33, 17, 1, 13, 24, 20, 41.5, 28, 10, 22, 49, 113,[1] 40, 42.4, 26, 88, 25. **100**: 33, 13, 20, 28, 22, 49, 40, 26, 25, 16, 46, 14, 73–80, 19, 35.5, 41, 47, 36, 44, 37, 7, 21. **110**: 28, 49, 40, 73–80, 41, 47, 44, 7, 21, 35, 15, 51, 93, 84. **120**: 44, 21, 51, 93, 84, 57, 87, 45, 38, 48, 59, 61, 37.5, 89, 62, 81. **130**: 93, 48, 59, 61, 56.5, 62, 63, 34, 72, 68, 91, 56, 65. **140**: 59, 34, 72, 68, 82, 91, 56, 65, 58, 83, 82, 55, 70. **150**: 34, 52, 91, 58, 83, 52, 53, 55, 70, 74, 82. **160**: 53, 55, 91, 58, 83, 54. **170**: 83, 86, 67, 60, 68.5. **180**: 83, 86, 67, 71. **190**: 86, 67, 71. **200**: 67, 71. **205**: 71. **260**: 92. **344.**

Fats and Waxes.—**4**: 135, 167, 144, 172, 103, 168–170, 117, 138. **10**: 167, 144, 168–170, 120, 101, 129, 100, 118, 133, 164, 102, 166, 96, 167, 140, 161. **20**: 96, 167, 137, 127, 146, 155, 161, 122, 132. **30**: 167, 137, 146, 155, 161, 122, 132, 125, 147, 123, 159, 151, 148, 98. **40**: 167, 137, 146, 161, 147, 159, 151, 98, 104, 131, 142, 100, 150, 152, 145, 109, 116. **50**: 167, 137, 150, 152, 145, 160, 105, 111, 110, 115, 99, 108, 153. **60**: 150, 152, 105, 111, 99, 108, 153, 106, 107, 128, 157, 126, 158, 130. **70**: 99, 157, 126, 158, 130, 134, 156, 96, 139, 121, 97. **80**: 158, 156, 121, 124. **90**: 158, 124, 113, 139.5. **100.**

23. SAPONIFICATION VALUE

50: 165, 166, 164, 167, 168, 169, 170. **100**: 167, 168, 170, 163, 162, 172. **150**: 136, 93, 84, 20, 94, 85, 72, 91, 24, 28, 19, 25, 6, 23, 27, 21, 90, 146, 143, 111. **180**: 84, 85, 91, 28, 19, 27, 21, 90, 143, 111, 146, 43, 108, 76, 16.7, 130, 9, 141, 50, 13, 66, 134, 7, 8, 137, 142, 51, 3, 88, 60, 123, 98, 44, 92, 34, 36, 148, 68, 106, 104, 38, 47, 62, 71, 4, 67, 86, 59, 96, 61, 87, 107, 149, 48, 83, 39, 54, 49. **190**: 84, 85, 28, 146, 130, 13, 8, 42.3, 68.5, 137, 142, 51, 139.5, 3, 123, 98, 44, 42.5, 92, 68, 104, 38, 47, 62, 71, 4, 67, 86, 59, 61, 87, 107, 149, 37.5, 48, 83, 39, 54, 49, 35, 80, 32, 99, 64, 17, 95, 81, 58, 160, 65, 63, 12, 78, 75, 18, 1, 16, 79, 153, 40, 5, 14, 73, 74, 125, 139, 110, 10, 26, 33, 57, 45, 69, 147, 15, 70, 29, 159, 30, 31, 105, 114, 157, 37, 113, 41, 52, 53, 55, 2. **195**: 84, 13, 8, 137, 142, 92, 86, 59, 49, 160, 65, 63, 40, 5, 14, 10, 26, 70, 29, 159, 30, 31, 105, 114, 157, 37, 41, 52, 53, 55, 2, 109, 152, 155, 156, 150, 112, 151, 115, 121, 126, 46, 116, 158, 131, 119, 56, 89, 135, 42, 144, 82, 42, 45.3, 41.5, 42.2,

[1] v. Table 3.

42.4. **210:** 37, 131, 135, 144, 161, 11, 145, 138, 100, 122, 154, 96, 100. **240:** 96, 100, 132, 133, 190, 97, 102. **250:** 89, 96, 133, 190, 118, 117, 101, 128, 103. **260:** 117, 140, 127, 89. **280:** 129, 85 **290.**

24. HEHNER VALUE

65: 88, 89. **82:** 97, 117, 127, 128, 129, 140, 161, 93, 17. **90:** 117, 93, 17, 120, 16.7, 144, 145. **92:** 3.5, 4, 16.6, 18, 28, 48, 51, 65, 66, 74, 77, 79, 84, 88, 95, 106, 108, 109, 111, 113, 119, 131, 132, 135, 138, 141, 142, 147, 149, 150, 153, 157, 160, 81, 87. **95:** 93, 119, 141, and all others for which data are available. **96:** 0.5, 12, 93, 119, 141, 86, 151. **97:** 29, 81, 87, 156, 158.

25. REICHERT-MEISSL VALUES

General index No.	Reichert-Meissl value	General index No.	Reichert-Meissl value
57	0.0	65	0.92
59	0 –1.2	31	0.9 –1.2
20	0 –0.79	119	0.9 –1.9
17	0.1	41	0.95
114	0.1	82	0.93–0.99
44	0.1 –1.3	67	0.95
123	0.11–1.54	5	0.99
91, 92	0.2	143	1
14	0.2	106	1 –2
124	0.22	131	1 –4
132	0.2 –0.4	42	1.02
43	0.2 –0.4	53	1.1
149	0.2 –0.4	125	1.1
153	0.2 –0.8	47	1.1 –1.2
146	0.2 –0.9	108	1.1 –2.5
160	0.2 –1.7	136	1.1 –4.2
26	0.28–0.48	54	1.2
142	0.3	83	1.2
147	0.3 –1.0	111	1.25–1.4
110	0.33	127	1.39
37.5	0.33	27	1.4
19	0.33–0.89	66	1.5
55	0.35	126	1.6
113	0.38	157	1.8
52	0.39	74	2.0
3	0.4	129	2.0
90	0.4 –0.7	50	2 –3
104	0.4 –1.31	4	2.5 –3.3
69	0.4 –3.0	128	2.53
105	0.44–0.88	133	3.0
28	0.46	95	3.4
7, 13	0.5	100	3.8
62, 138	0.5	51	4.2 –9.9
112	0.5	140	4.5
48	0.5 –2.8	38	4.45
86	0.5 –1	120	5 –6.8
159	0.5 –1	88	5.6
36	0.55	96	5.7 –7.2
2, 69	0.6	102	5.8
141	0.6	103	6.3
107	0.6 –0.5	117	6.6 –7.5
8	0.6 –1.8	101	8
116	0.65	134	8.27
155	0.68	145	9
158	0.7 –2.8	84	14
23	0.75	161	17.0–34.5
22	0.75	154	20.8–27.7
81	0.75	89 (Body)	64.9
130	0.8 –0.9	88 (Jaw)	65.9
11	0.88	89 (Jaw)	132

26. UNSAPONIFIABLE MATTER

General index No.	%	General index No.	%
31	0.12–0.65	84	1 –4
115	0.19	139	1.1
134	0.25	144	1.1 –1.6
92	0.3 –1.0	57	1.14
103	0.36	51	1.25–1.60
52	0.41	48	1.27–1.54
8	0.4 –1.0	74	1.3
67	0.4 –1.2	68.5	1.3
69	0.43	32	1.30–2.65
5	0.5	104	1.36
54	0.5 –0.9	82	1.45
107	0.5	139.5	1.6
3	0.5 –0.9	88	2
87	0.5 –3.0	50	2.4 –2.6
125	0.5	95	2.61
62	0.51	10	3
155	0.52	25	3.3
91	0.54–2.68	108	3.86
53	0.59	93	2.8 –15.2
29	0.6	111	5 –9
83	0.6 –1.45	133	7.0
90	0.7 –7.0	94	8.4
13	0.75	89	16 –17
100	0.75	137	20.4
86	0.98	162	36 –41
55	0.99	167	39 –44
85	1 –2	166	47
58	1.08	172	51.5
37.5	1.1	164	54 –55
41	1.1	94.5	1 –90

27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C	General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
71	–5		51	17 –22	19
64	0		45.3	18	
75	0		20	18.5–20	11.7–13.6
77	0		18	19	10
14	2.3– 4.5		76	19	
162	10.3–10.8	8.3– 8.6	15	19 –21	13 –15
128		9 –10	23	20	13 –15
59	11 –17	7 –12	21		13.5–16.5
163	13.4		63		15 –20
13	13 –14	9.5–11.8	69	20.5	17 –19
34	13 –14		56		17.6
16	13.4–18		67	20 –24	16 –21
84	14 –27	10 –24	96	20.5–21	
82	14.5		60	21.5	
127		13		(begins)	
65	15 –20	14.3		65.0	
25	16 –17	13.4–13.7		(complete)	
43	16 –18		37		17 –19
78	16 –19	10 –16	45	21.7	22 –26
79		10 –15	93	21 –22	
58	17 –21	15.6–16.6	91	21.8–38	17.5–24.3
12	17 –20		5	22 –25	19 –20

27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS.—(*Continued*)

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C	General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
92	22 –23		39	38	
62	22 –24	18 –19.8	4	38.8	
66	22.2		157	38 –40	32 –34
57	22.8		161	38 –41	33 –39
46	23		50	39 –40	
28	23 –25		30		35 –37
40	23 –24		158	39 –50	35 –41
36		19.7–21.0	146	39 –57	45.2–47.2
68	23 –26	20 –24			50.9–52.5
103	23.6		105	39 –45	38 –40
26	24 –30		42.4	40	
133	24.2		106		38 –41
117	24 –27	21.2–25.2	114	40 –42	37 –40
120	25 –28.5	20 –25.5	42.2	41	
61	25.4	22.6	167	41.8	
94.5	25 –35		109	42 –46	38 –40
47	25 –35	23 –32	130	42 –49	
8	26 –30	16.9–26.4	151	42.5–44	37.9–46.2
48	26.2–27.5		138	42.5–46	
100	27		42.1	43	
140	27 –28		42.5	43	
101	27 –28		143	44 –45	36 –42
124	27 –45	39.9–51	42	46	
32	27.5		137		37.2
33	28 –30	31.1–32.2	160		42.5–44
31	29 –41	16 –26.5	159		40 –50
81	30 –40		42.3	47	
27	30		135	47 –48	
85	30 –32		116	48.3–50	46 –47
38		26 –28	147	48 –53	47.2–49.2
113		28 –29	108	49 –52.8	47
86	30 –34.8	28.2	119	50	42.5–45.5
3		30.5–39	141	50 –57	
52	30 –49.4	36 –39	155	50 –64	46 –50
90	31		131	51 –55	48 –52
97	31		148		48.1
156	31.3–53.4		111	52 –53	
112	33 –34		145	52 –55	49.7–50.7
29	33 –38.4		144	53 –56.5	
152	33.5–49	40 –48.5	41.5	55	
41	34.5		125	56	
132	35		107	56	
87	35 –36	27.5–28.2	149	56 –57	
99	35 –38		142	57 –60	
153	36.6–40	31 –34	104	58.4	
95	36.5	27 –28	98	59	61.4–61.5
150	37 –46.6	36 –42.4	123	60 –61	
6	37.6				

HYDROGENATED OILS

Hydrogenation reduces the iodine value, and refractive index, ([56]) but has little influence upon the acid value, saponification value and unsaponifiable matter.

In oils, such as castor oil, containing hydroxyl groups, the hydroxyl value is lowered ([143]). The amount of insoluble bromides is reduced. The stearic acid formed on hydrogenation is identical with normal stearic acid ([120]).

A method of differentiating hydrogenated and natural oils has been based on the ratio between the amounts of stearic acid and palmitic acid ([135]). Hydrogenated oil may be recognized by a determination of the iso-oleic acid formed in the process ([208]).

Partly Hydrogenated Oils ([218])

General index No.	Oil	M. P., °C	Congelation point, °C	Butyrorefractometer reading (40°)	Acid value	Saponification value	Iodine value
117	Coconut	44.5	27.7	35.9	0.4	254.1	1.0
47	Sesame (techn.)	62.1	45.3	38.4	4.7	188.9	25.4
84	Whale	45.1	33.9	49.1	1.2	192.3	45.2
3	Arachis	51.2	36.5	50.1	1.0	188.7	47.4
47	Sesame	47.8	33.4	51.5	0.5	190.6	54.8
41	Cottonseed	38.5	25.4	53.8	0.6	195.7	69.7

Whale Oil (Gen. Ind. No. 84) at Different Stages of Hydrogenation ([219])

	M. P., °C	Congelation point, °C	Acid value	Saponification value	Iodine value	Molecular equivalence of fatty acids
Original oil	Fluid	Fluid	9.50	192.2	144.8	287.7
Artificial tallow	47.5	38.1	9.88	183.7	56.9	296.4
Artificial stearine	54.3	47.3	7.80	187.7	11.7	297.0
Hydrogenated whale oil	41.9	31.9	5.30	190.9	57.8	282.9

Completely Hydrogenated Oils ([220])

General index No.	Hydrogenated oil or fat	M. P., °C	Iodine value	Saponification value	Fatty acid, M. P., °C
159	Tallow	62	0.1	197.7	64
150	Lard	64	1.0	196.8	62
147	Cacao butter	63.5–64	0.0	193.9	65.5
3	Arachis	64–64.5	0.0	191.6	67
91	Cod liver	65	1.2	186.2	59
67	Linseed	68	0.2	189.6	70.5
47	Sesame	68.5	0.7	190.6	69.5
8	Olive	70	0.2	190.9	71
69	Poppy	70.5	0.3	191.3	71
13	Almond	72	0.0	191.8	71

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ADHESIVES AND GELATINS

JEROME ALEXANDER

INTRODUCTION

Most practical adhesives are mixtures of several ingredients, with or without some kind of salt, and may be classified as:

(*A*) Animal adhesives: *e.g.*, glues, gelatins, casein, albumin;

(*B*) Vegetable adhesives: *e.g.*, flours, starches, dextrins, gums, gum resins, oils, and proteins;

(*C*) Mineral adhesives: *e.g.*, silicate of soda, cements, limes, plasters, clays, pitches, tars, artificial resins, solders, and such mixtures as iron + sulfur and litharge + glycerin.

In using an adhesive to join two surfaces, the surfaces concerned are the ultimate exterior ones and the adhesive must either take hold of these exterior surfaces or must remove them and take hold on the surface below. Thus, if the articles to be joined are not cleaned, the exterior surface is frequently a layer of grease.

Setting and drying are promoted by any agency which increases the concentration of the adhesive; for example, by removing the solvent. Joint strength is influenced by quantity of adhesive used, by speed of set and drying, and by the application of pressure.

Animal Glues

Use.—(1) Keep dry and from excessive heat; (2) use definite weights of glue and water; (3) soak glue in cold water until softened; (4) melt on water bath and keep temperature as low as work permits (usually below 65°C); melt small batches successively to avoid prolonged heating which injures strength; (5) supply evaporation losses; (6) use clean vessels, and, if necessary, a preservative.

Selection

Wood Joints.—Hide-stock glues, grades 70–130.[1] Joining pressure before setting increases joint strength rapidly up to 200, and then more slowly up to 1000 lb./in.^{2}. Surfaces must be well joined, dry, and preferably warm. Good joints are stronger than the wood, and may show shearing strength of 2000 to 3000 lb./in.^{2}

Veneers.—Bone and hide stock mixtures between 50 and 70. Avoid foam.

Paper Boxes.—For hand setting-up, 70 to 90 test; for machine, 100 to 160 test. For covering or stripping, 30 to 60 test.

Book Binding.—For rounding and backing, grades above 90 are best (usually mixed with some glycerin). For hand pasting, grades about 50. For case-making machines, grades 60 to 100.

Leather Belting, Printer's Rollers, Plaster Molds.—Hide glues above 120; usually with addition of glycerin, etc.

Gelatins

Photographic Gelatin (1).—Jelly strength, 130 or above. pH, 5–6 (limit 4–7). Ash <3%. Fe and Cu <50–60, Pb <50, parts per million. Al_2O_3 <0.2%, SO_2 <0.1%, of dry gelatin. Mucin, grease, and ammonia ≯ traces. Traces of thiocarbimides are essential (55).

Food Gelatin.—U. S. Dept. of Agriculture, Bureau of Chemistry, tolerance limits (parts per million): As_2O_3, 1.4; Zn, 100; Cu, 30; Pb, 20; SO_2 must be declared on label.

1. ADHESIVES

Comparison of American Grades of Glue and Gelatin (1, 5, 22)

Cooper	Alexander			Bogue	National Assn. Glue Mfrs. (U. S. A.)		
Grade	Grade	S*	η†	Grade	Grade	S‡	η§
	10		15.5 ± 0.25		1	10	20
	20		16 ± 0.25	1	2	27	24
2	30		16.5 ± 0.25	2	3	47	28
1 7/8	40	1701	17 ± 0.25	3	4	70	32
1 3/4	50	2324	18 ± 0.5	4	5	95	37
1 5/8	60	2948	19 ± 0.5	5	6	122	42
1 1/2	70	3572	20 ± 0.5	6	7	150	47
1 3/8	80	4196	21 ± 0.5	7	8	178	53
1 1/4	90	4820	22 ± 0.75	8	9	207	60
1 X	100	5443	23 ± 0.75	9	10	237	67
1	110	6067	24 ± 0.75	10	11	267	75
1 Extra	120	6691	25 ± 1	11	12	299	83
A Extra	130	7314	26 ± 3	12	13	331	92
	140		28 ± 5		14	363	102
	150		34 ± 8		15	395	113
	160		40 ± 12		16	428	125
					17	461	138
					18	495	152
					19	530	167
					20	565	183
					21	600	200

* Jelly "strength" in grams, Alexander tester.
† Viscosity in seconds (water = 15).
‡ Lower limit of jelly "strength" in grams, Bloom gelometer.
§ Viscosity in millipoises, lower limit.

Specific Gravity of Glue Solutions (40)

Wt. % glue	d_{75}^{75}	°Bé, 54.4°C	°Bé, 32°C	°Bé, 15.6°C
7	1.001			
8	1.003			
9	1.006			
10	1.009	2.2	3.1	4.0

[1] The "grades" here referred to are the Alexander grades listed in Table 1.

Specific Gravity of Glue Solutions (40).—(*Continued*)

Wt. % glue	d_{75}^{75}	°Bé, 54.4°C	°Bé, 32°C	°Bé, 15.6°C
15	1.023	4.2	5.1	6.0
20	1.037	6.1	7.0	7.9
25	1.051	8.0	9.0	9.8
30	1.065	9.8	10.7	11.6
35	1.079	11.5	12.4	13.3
40	1.093	13.2	14.1	15.0
45	1.107	14.9	15.7	16.5
50	1.121	16.5	17.4	18.3

Nitrogen Content of Glues, Wt. % (10)

H = hide glue; B = bone glue; F = fish glue; P = protein; I = isinglass

Form	H*	B*	F	P	I
Ammonia	2.9	4.6	5.2	1.3–3.6	4.0
Melanin	0.6	0.9	1.1	0.7	0.7
Cystine	0	0	tr	tr	0
Arginine	13.9	13.2	13.8	11–12.6	14.2
Histidine	2.2	1.8	2.0	0.8–2.2	2.3
Lysine	8.0	8.3	8.6	8.3–8.6	6.1
Amino†	56.8	56.3	60.2	58–60	58.7
Non-amino†	15.6	15.3	9.7	15.5	13.6

* Av. of 6 samples.
† Soluble.

Joint Strength

The strength of joints made with an adhesive depends upon the kind of material joined and the condition of its surface, upon the thickness of the adhesive film, and upon such conditions as temperature, humidity, time of drying, and pressure used in forming the joint.

Tensile Strength (Def. 4): Oak to Oak (32)

Unit: kg/cm^2

Effect of air humidity and temperature

At t°C			15°	20°	25°	25°
Air humidity			50%	75%	90%	95%
Liquid glues	A	*	49.6	45.8	35.4	26.4
	B	*	45.7	44.1	39.1	29.0
	C	†	31.7	31.3	31.1	30.3
	D	†	42.7	41.2	39.4	37.7

* Very hygroscopic.
† Slightly hygroscopic.

Tensile (TS) and Shearing (SS) Strength of Metal to Metal Joints (21)

A = High grade commercial gelatin. B = Silicate of soda. C = Commercial nitrocellulose cement "A." D = Molten shellac (pure). E = American commercial cement (hard). F = American commercial cement (medium). G = A wax. H = Fish glue. I = Liquid commercial glue "C." J = Rubber solution. K = Marine glue. L = Commercial glue "B." M = Gum arabic. T = Drying or setting time in days. Stl. = Mild steel. Fe = cast iron. Bra. = Brass. Unit: kg/cm^2.

Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
A	17	TS	63	70	77	84	49	(21)	56	56
	20	SS		70	49	56	77		35	
B	20	TS	35	49†	49	56‡	70	49	35	21
C*	14–21	TS	112	112	98	140	105	119	70	35
	21	SS		49	56	35	35	56	42	28

Tensile (TS) and Shearing (SS) Strength of Metal to Metal Joints ([21]).—(*Continued*)

Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
D	1–5	TS	246	225	211	232	176	197	77	42
	1–3	SS		239	211	232	232	155		
E	1–2	TS	295	337	309	281	204	162	105	35
	1–3	SS		295	288	288	267	218	77	42
F	1	TS				309		169		
	1	SS		260	225	239	246	147		
G	1–2	TS	84	70	98	70	77	70	56	35
	· 1	SS	35			35	42	42	42	35
H	16	TS	84	56	84	98	49	70		
	16	SS	35	98	84	77	98	(14)		
I§	18	TS				21		28	28	
	18	SS		35	28	35	21	21		
J	16	TS			21					
K	4–5	TS	77	120	63		105	98	56	
	4–5	SS	42	84	56	42		63	63	
L	77	TS	88	133	112	112	140	70	77	
	77	SS	88	112	106	105	84	91		
M	77	TS	84	63	77	112	112	49	56	
	77	SS	(98)	88	70	(112)	56	105	56	

* TS = 28 with amalgamated Cu and 77 with platinized Cu.
† When rough = 21, oxidized = 35.
‡ Amalgamated Cu.
§ TS = 28 with platinized Cu.

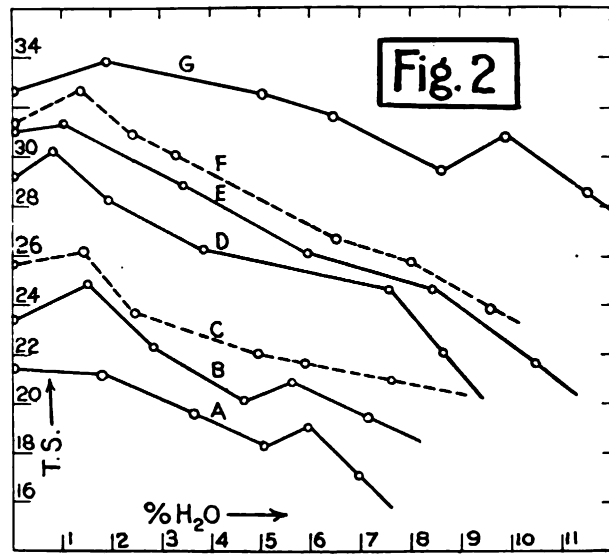
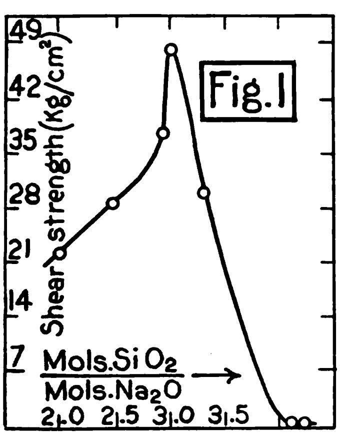
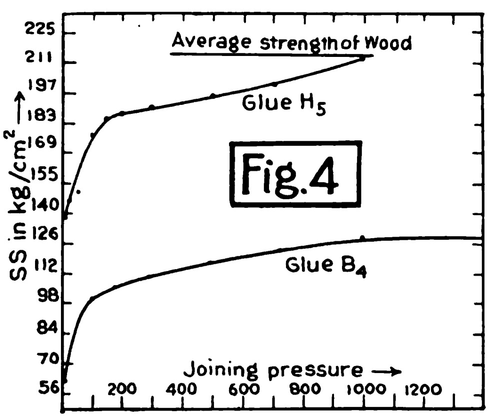


Fig. 2.—Effect of moisture content on joint strength ([2]). A, B = bone glues. C, D, E, F = hide glues. G = gelatin.





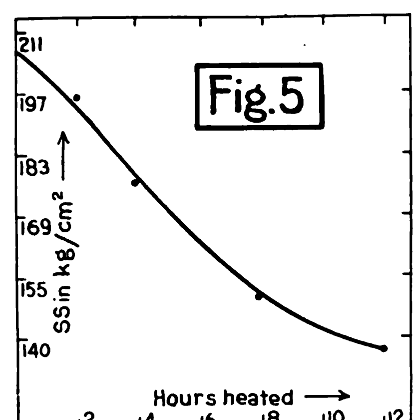


Fig. 1.—Shearing strength of water-glass joints between walnut surfaces ([21]).

Fig. 4.—Effect of joining pressure ([11]). Shearing strength of wood to wood joints with a hide glue H_5 and a bone glue B_4.

Fig. 5.—Effect of heat ([11]). Shearing strength of wood-to-wood joints made under constant joining pressure of 14 kg/cm² using a glue heated to 80°C.

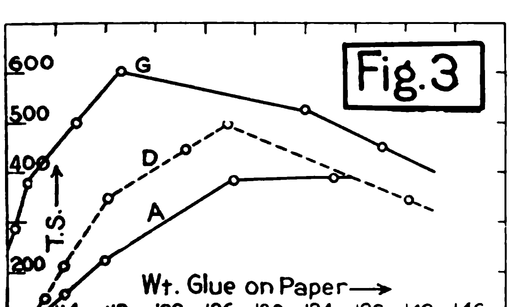


Fig. 3.—Effect of film thickness ([2]). TS = tearing strength, in kg/cm², of glue.

Shearing Strength, Walnut to Walnut ([21])
Unit: kg/cm²

Adhesive	Days dried	kg/cm²
Fish glue	7	98
Liquid commercial glue "C"	7	84
High grade gelatin	6	84*
Fish glue + bone gelatin	7	49
Casein + borax cement	6	42
Gum arabic	6	28
Commercial glue "B"	12	28
Casein and silicate cement	8	21
Commercial nitrocellulose cement "A"	30	21
Starch	9	21†

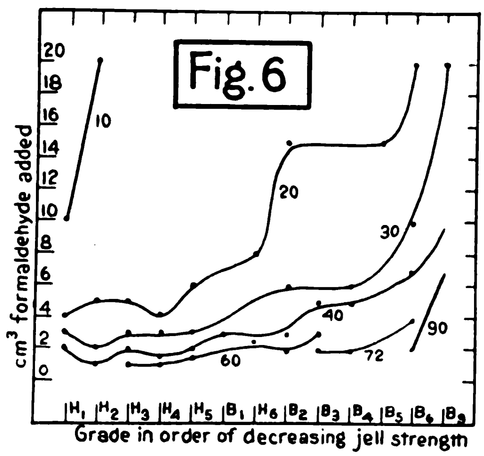
* Reduced to about 30 if the joint be heated to 100° for 4 days while clamped.
† Film not complete. Three coatings raise value to 112; values have been measured as high as 600. Additional data are given in Figs. 1–5.

Tensile Strength of Some Common Adhesives
Unit: kg/cm²

Glue (calculated)	700–2000
Collagen	1300
Gelatin	960
Viscose	2100

Jelly Strength

The jelly strength of a glue is usually measured by the force required to cause a definite compression of the jelly. The addition of formaldehyde to glues decreases the jelly strength in direct proportion to the amount of HCHO added, until the glue becomes insoluble. Figure 6 shows the number of cm³ of 10% HCHO required to produce insolubility in various glues, the numbers on the curve giving the grams of glue to 180 g total weight of solution ([7]).



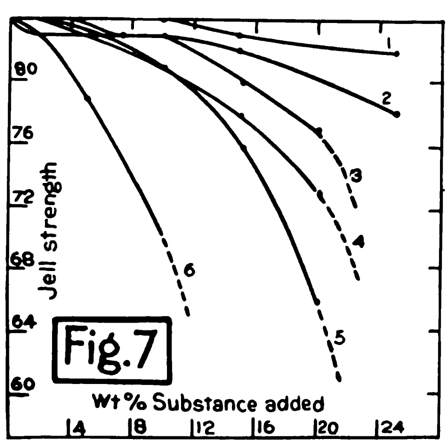


Figure 7 shows the effect of added substances upon the jelly strength. 1 H_2SO_4; 2 NaOH; 3 $MgCl_2$; 4 Acetic acid; 5 Chloral hydrate; 6 KI. 1 and 2 in cm³ of 0.5*N* soln. added instead of wt. % ([7]).

The relation between the nitrogenous constituents and the jelly strengths of hide (H) and bone (B) glues is shown in Figs. 8 and 9 ([9]).

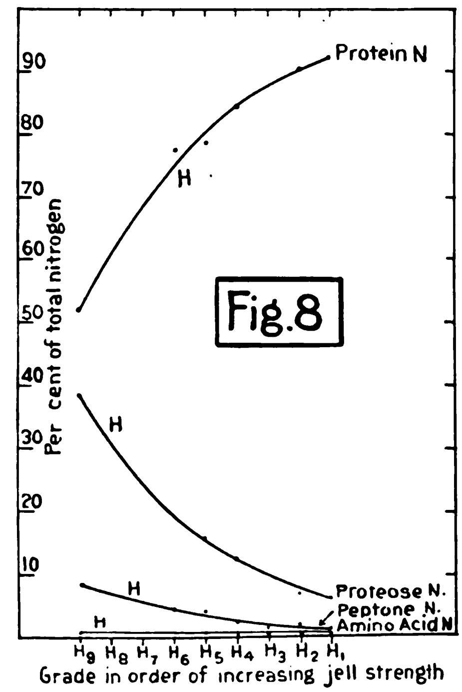
Viscosity; η

The viscosity of 20% solutions of hide and bone glues at 15.5°C (60°F) is constant for at least 90 minutes after preparation. Vigorous agitation lowers η slightly (2% after 2 minutes beating) ([7]).

The increase in η produced in dilute solutions of glues by formaldehyde is slight, but rises rapidly with increasing glue content. Agitation increases η of HCHO treated glues slightly and after drying such glues exhibit increased η on re-solution or become insoluble with increasing HCHO content ([7]).

The amount of protein precipitated by 24–30% $MgSO_4$ solution from liquid glue varies directly as η for glue solutions having the same jelly strength ([9]).

The amount of material absorbable from glue solutions decreases as η decreases ([34]).



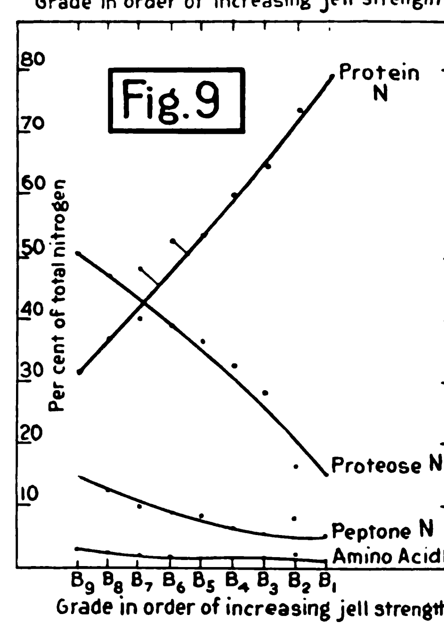


Figure 10 shows the effect of time on η (in seconds, H_2O = 42) of HCHO treated glues and Fig. 11 the effect of temperature. (Numbers on curve = cm³; 10% HCHO added.) ([7]).

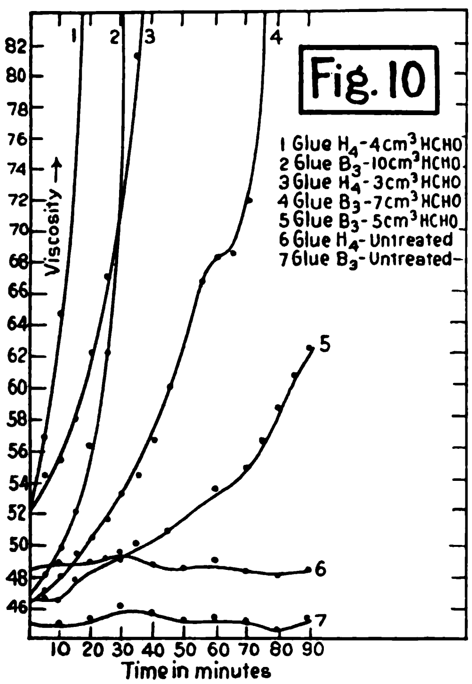
Figure 12 shows the effect of alums on η of glue solutions; Fig. 13 the effect of time, and Fig. 14 the effect of temperature on the η of alum-treated glues ([7]).

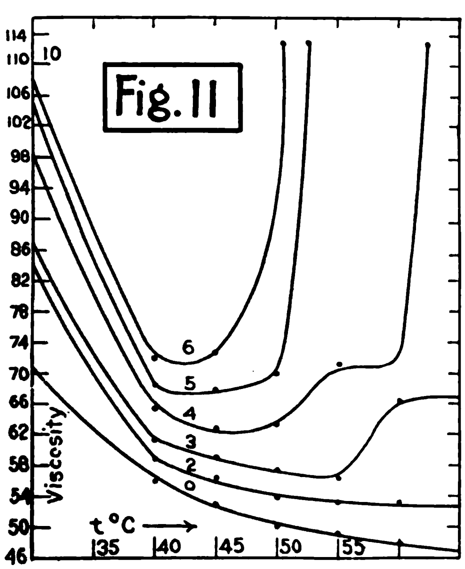
Figure 15 shows the variation of η (in seconds, H_2O = 42) of glue solutions with temperature, the melting point of the glue solution being taken as temperature at which the slope of the curve approaches infinity ([8]).

Figure 16 shows the effect of temperature on the η of hide glues, and Fig. 17 on the η of bone glues (η in MacMichael degrees) (8).

Figure 18 shows the relation of η to jelly strength of hide glues (11).

The flow of starch pastes, under pressure, through a capillary tube is shown in Fig. 19 and of dextrin pastes in Fig. 20. The numbers on the curves give the wt. % of dry solids in the pastes (16).





The η of 10% hide and glue solutions, measured at 35°C, is decreased considerably by heating under pressure up to 5 atm. for 1 to 5 hr. (23).

Addition of anhydrous chrome alum in small percentages has little or no effect on the η of glue solutions (33).

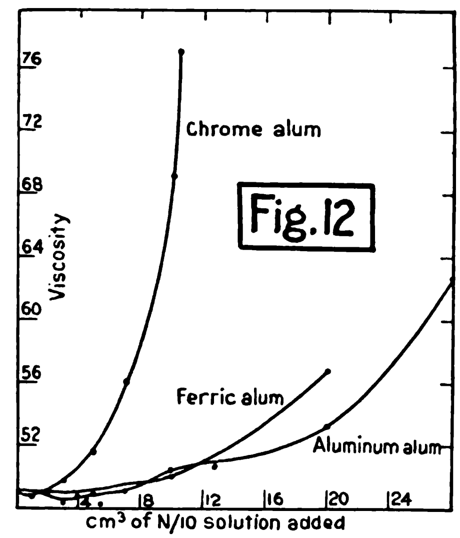
Gelling point

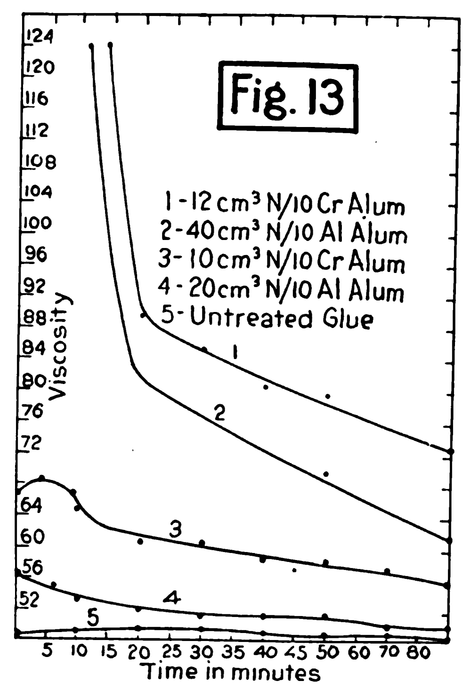
The gelling point of a glue is the temperature at which appreciable flow under the action of gravity ceases.

Chrome alum (anhydrous salt = 0.8% wt. of dry glue) raises the setting or gelling point *ca.* 2°C with 20% glue solutions and *ca.* 10° with 50% glue solutions. The gelling points (in °F on curves) of glue solutions as affected by addition of chrome alum are shown in Fig. 21 (33).

Drying Behavior

High grade liquid glues lose water much more slowly than low grade glues when dried at room temperatures (2).





2. GELATINS

Jelly Strength

Alcohol up to *ca.* 25 vol. % tends to increase the rigidity of 10% gelatin gels; larger amounts cause a decrease. Acetone acts similarly (20).

According to Bogue (15) the maximum jelly strength occurs at pH = *ca.* 4, and minimum at pH = *ca.* 5, near the isoelectric point. Sheppard and Sweet (27) find the maximum at the isoelectric point, pH = 4.7, with a minimum at pH = *ca.* 5.5 and a second maximum at pH = 7.8.

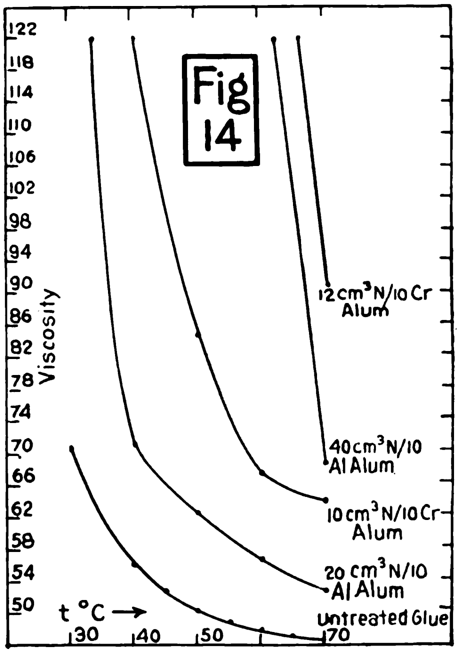


Fig 14
Viscosity
t °C →
12 cm³ N/10 Cr Alum
40 cm³ N/10 Al Alum
10 cm³ N/10 Cr-Alum
20 cm³ N/10 Al Alum
Untreated Glue

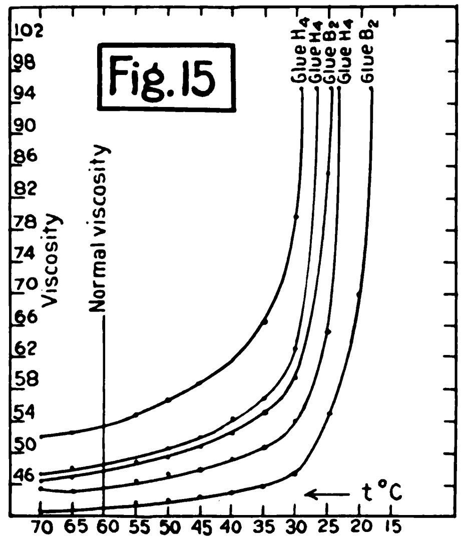


Fig. 15
Viscosity
Normal viscosity
Glue H4
Glue H4
Glue B2
Glue H4
Glue B2
← t °C

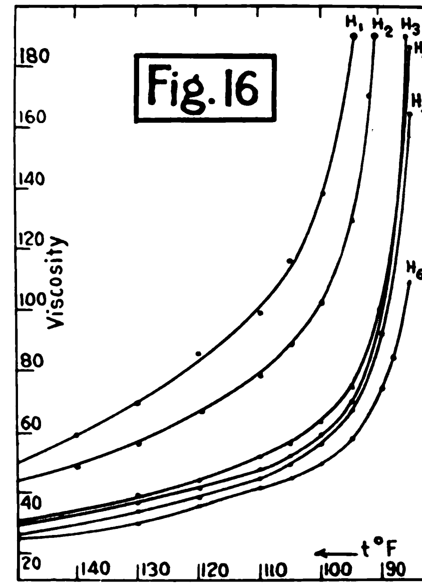


Fig. 16
Viscosity
H1
H2
H3
H4
H5
H6
← t °F

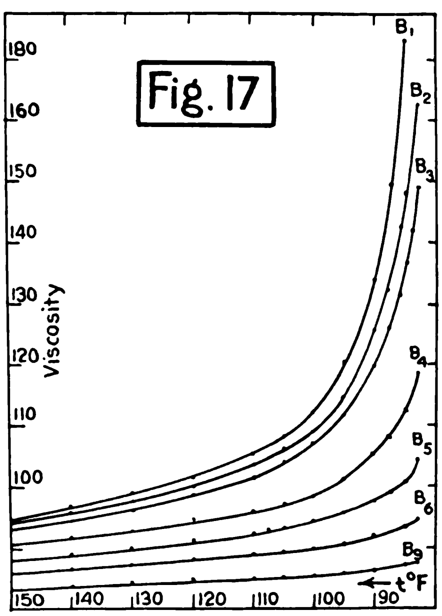


Fig. 17
Viscosity
B1
B2
B3
B4
B5
B6
B9
← t °F

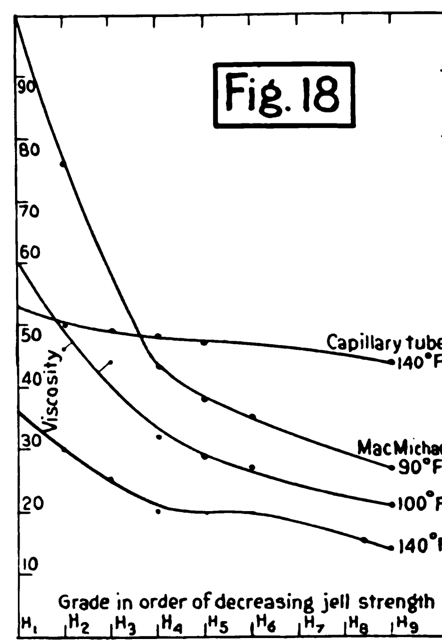


Fig. 18
Viscosity
Capillary tube
140°F
MacMichael
90°F
100°F
140°F
Grade in order of decreasing jell strength
H1 H2 H3 H4 H5 H6 H7 H8 H9

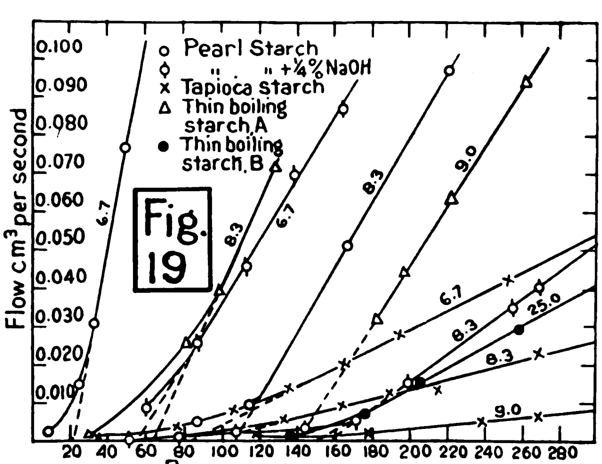


Fig. 19
Pearl Starch
" " +¼% NaOH
Tapioca Starch
Thin boiling starch, A
Thin boiling starch, B
Flow cm³ per second
Pressure, grams per sq. cm.

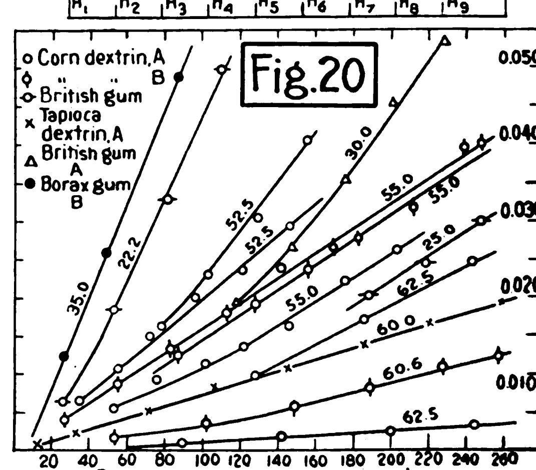
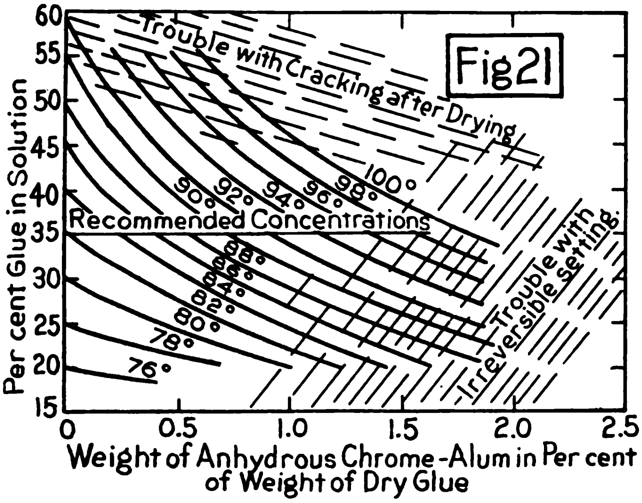
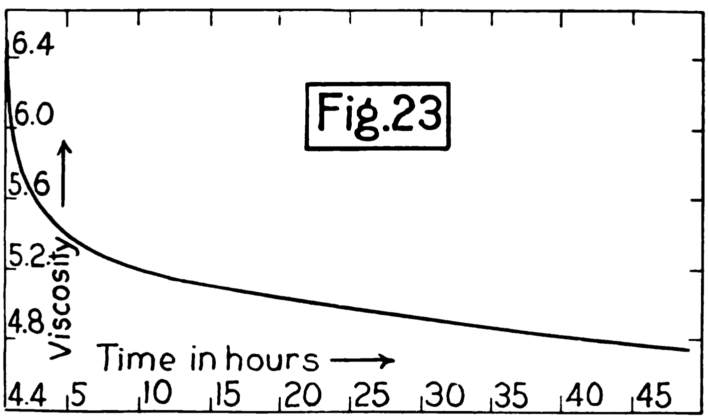


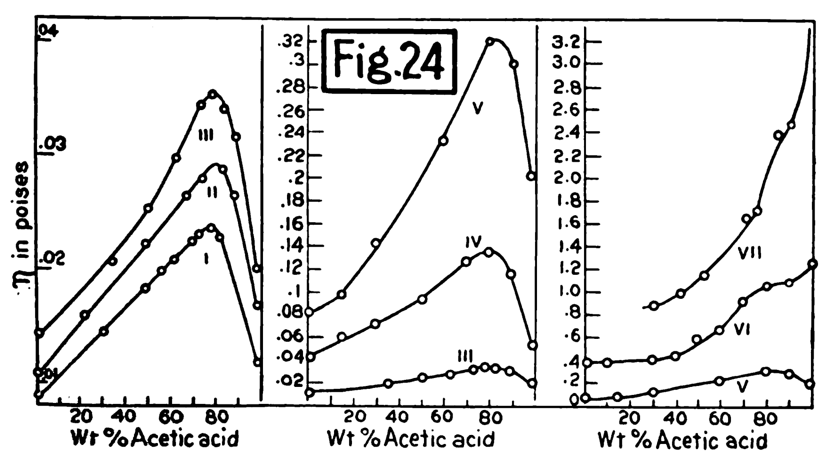
Fig. 20
Corn dextrin, A
" " B
British gum
Tapioca dextrin, A
British gum A
Borax gum B
Flow cm³ per second
Pressure, grams per square centimeter

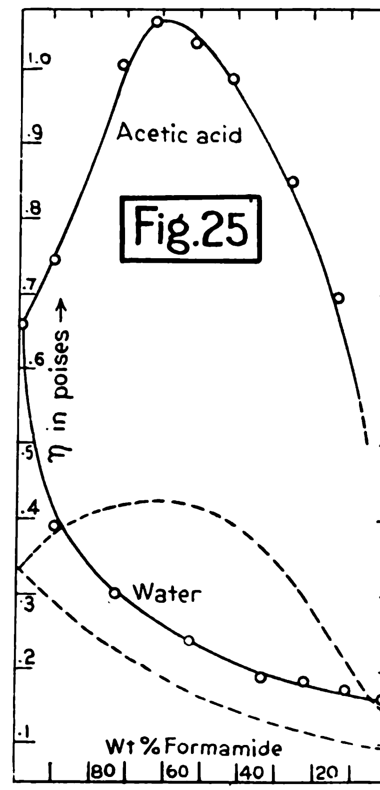
Figure 22 shows the influence of traces of Al salts on the rigidity of a 7% gelatin jelly ([28]).

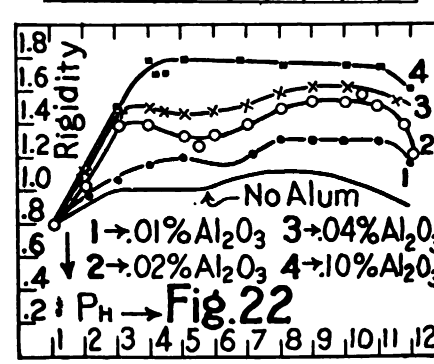
For the effect of sulfuric, phosphoric and lactic acids on jelly strength, *see* ([4]).











Adhesive Strength

Slight hydrolysis increases the adhesive strength of high-grade gelatin, while continued hydrolysis decreases it ([13]).

Viscosity

Gelatin in aqueous solution, as measured by the MacMichael viscometer, follows the laws of viscous flow at temperatures above *ca.* 40°C, but exhibits the properties of plastic flow below the solidification point. The sol-gel transformation occurs over a range rather than at a point. At 35°C, time rate of change of η varies with the pH of the solution, the concentration and nature of inorganic ions, and the amount of hydrolyzed protein present ([3]).

Figure 23 shows the variation of η at 35°C (in arbitrary units) with time for a 5% purified photographic gelatin, pH = 4.9 ([18]).

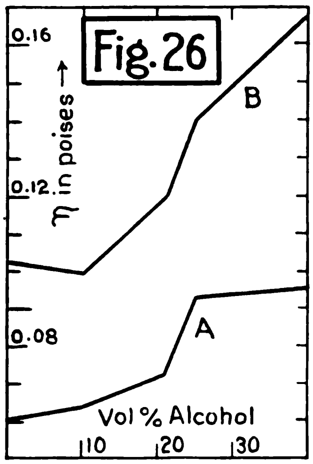
The η at 25°C of solutions of gelatin in aqueous acetic acid is given in Fig. 24. Curve (1) is for the two liquids alone, (2) for 0.2 g gelatin per 100 cm³ of solution, (3) for 0.6 g, (4) for 5 g, (5) for 10 g, (6) for 15 g, (7) for 20 g per 100 cm³ ([20]).

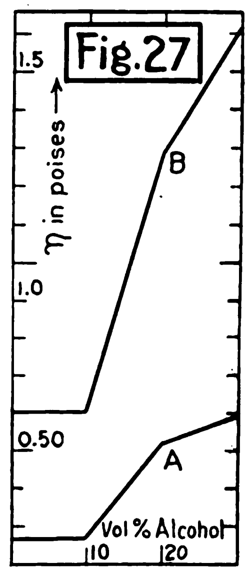
The η at 25°C of solutions of gelatin (10 g per 100 cm³) in formamide + water and formamide + acetic acid is given in Fig. 25. The dotted curves are the η of the mixtures without the gelatin ([20]).

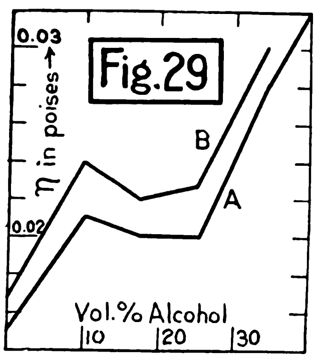
Figure 26 shows the η at 28°C of solutions of gelatin (5 g per 100 cm³) in methyl alcohol-water mixtures. A = η of fresh solution; B = η after 30 min ([20]).

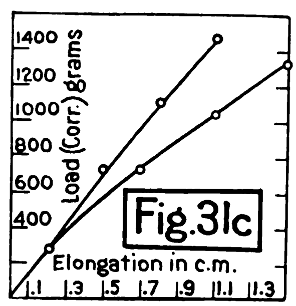
Figure 27 shows η at 30°C of solutions of gelatin (15 g per 100 cm³) in methyl alcohol-water mixtures. A = freshly prepared; B = after 15 min ([20]).

Figure 28 gives η at 25°C of solutions of gelatin (2 g per 100 cm³) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min ([20]).









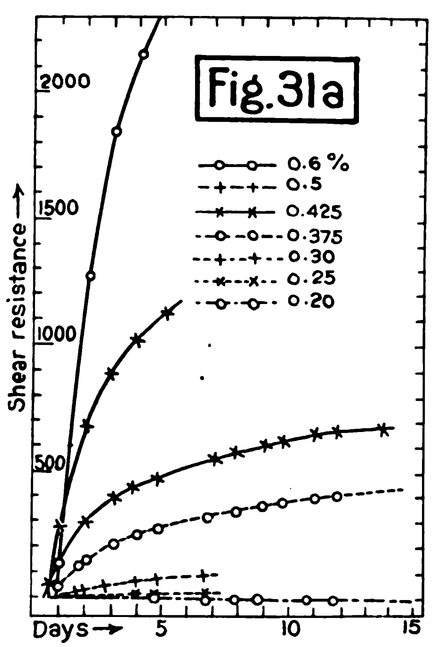
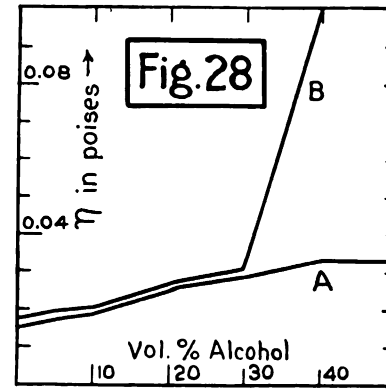
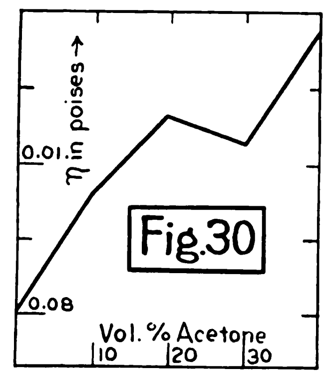
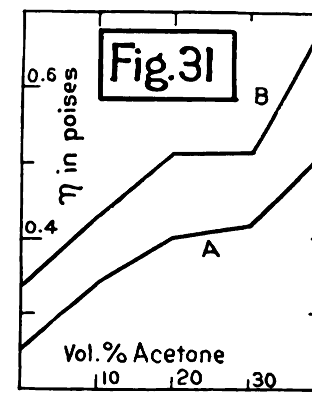


Figure 29 gives η at 30°C of solutions of gelatin (10 g per 100 cm³) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min ([20]).

Figure 30 gives η at 35°C of solutions of gelatin (10 g per 100 cm³) in acetone-water mixtures ([20]).







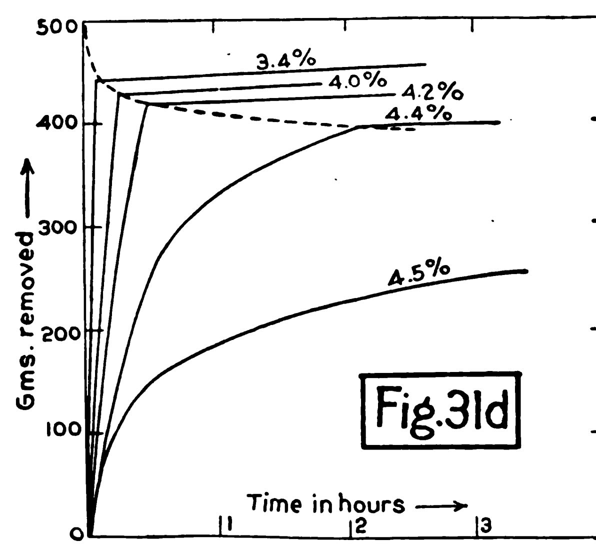


Figure 31 gives η at 30° of solutions of gelatin (15 g per 100 cm³) in acetone-water mixtures. A = freshly prepared; B = after 15 min ([20]).

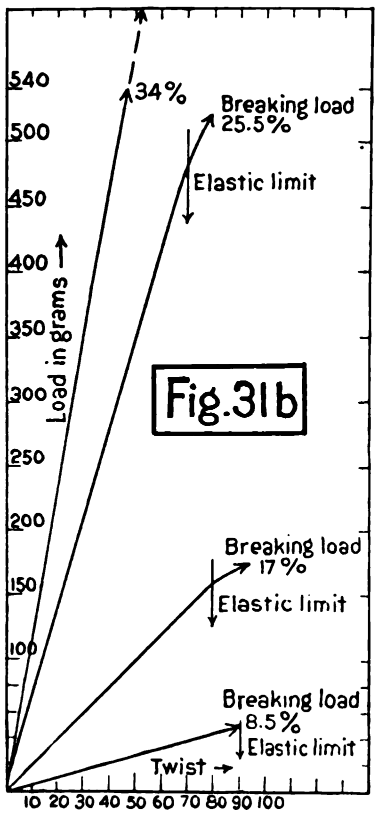
The addition of pyridine to solutions of gelatin in water increases η, while addition of dimethylamine and diethylamine up to *ca.* 25 wt. % of solution decreases, and over 30% again increases η ([20]) *cf.* ([45, 46, 47]).

Plasticity and Elasticity

The temperature at which plasticity appears in gelatin solutions depends both on the concentration and on the way in which the solution is prepared ([49]).

Figure 31*a* gives the change with time of the elastic resistance to shear of dilute gelatin solutions (0.2–0.6%) at 8°C ([50]).

Figures 31*b* and 31*c* show the behavior of gelatin jellies under torsion and stretch, respectively. The gelatin content of the jellies is given in wt. % ([51]).



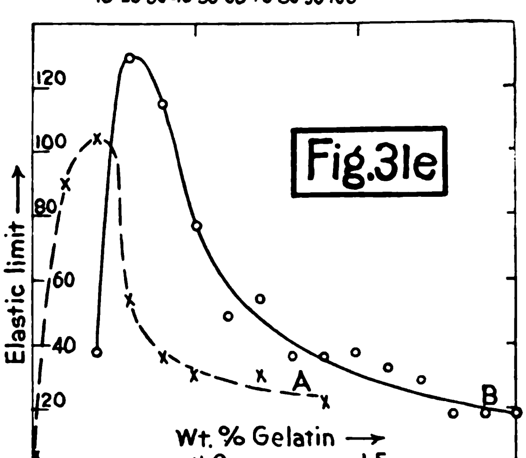


Figure 31*d* shows the behavior of gelatin jellies (3.4–4.5 wt. % gelatin) which have been under a load of 500 g at 16.5°F. The portion of the load removed in order to keep the deformation constant is given as a function of time ([52]).

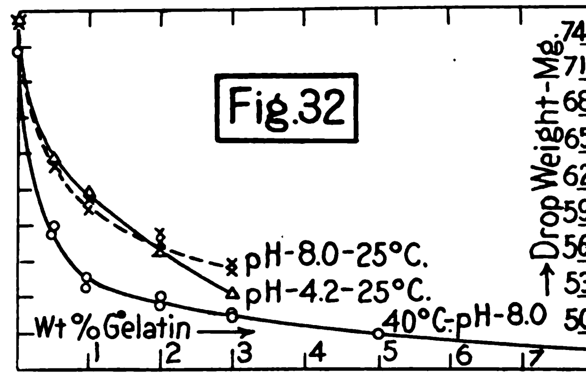
Figure 31*e* shows the relation between the elastic limit of gelatin solutions and the concentration of the gelatin in the solution. A = purified gelatin; B = a commercial gelatin.

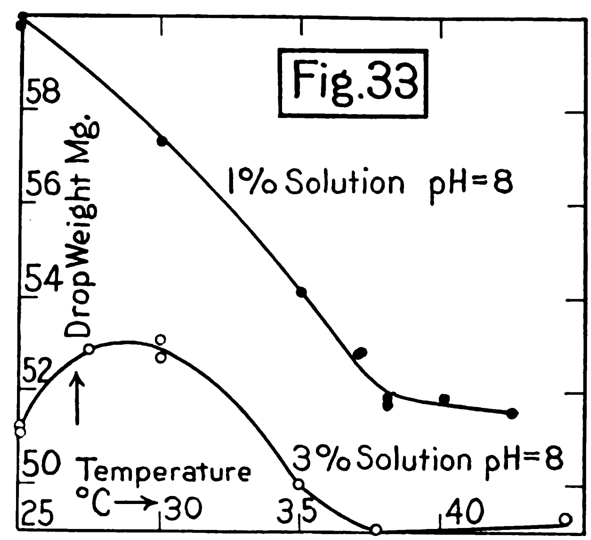
Surface Tension; γ

Figure 32 shows the variation in the drop-weight of water solutions of ossein gelatin with varying concentrations of gelatin ([13]).

Figure 33 shows the variation of drop weight of gelatin-water solutions with temperature, and Fig. 34 with pH ([13]).

Figure 35 shows the effect of pH on the drop weight of various gelatin-water solutions containing 0.5% gelatin ([13]).





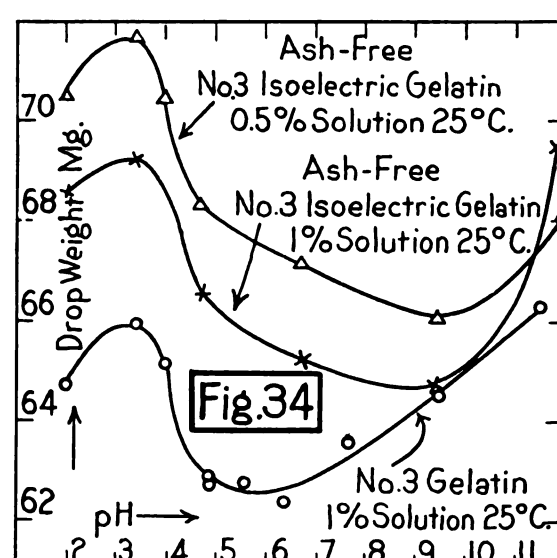
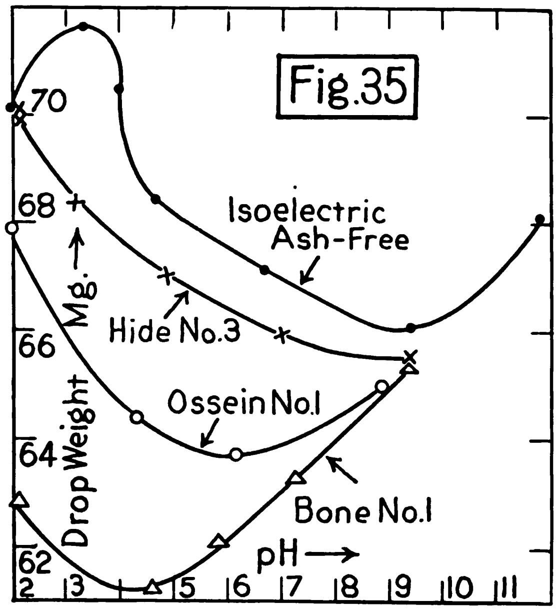
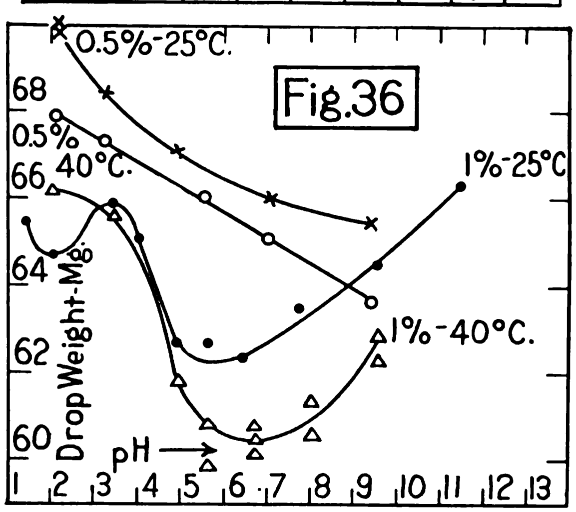


Figure 36 shows the effect of pH on a hide gelatin (0.5 and 1 wt. % of gelatin) solution in water at 25° and 40°C ([13]).

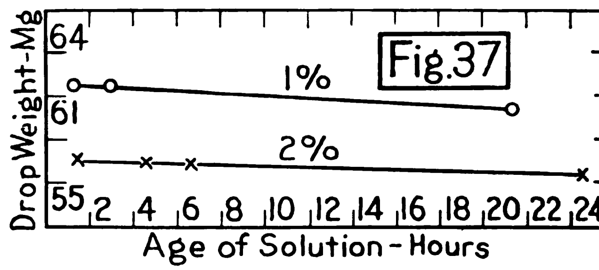
Figure 37 gives the variation in drop weight of 1 and 2% gelatin in water solutions with time ([13]).

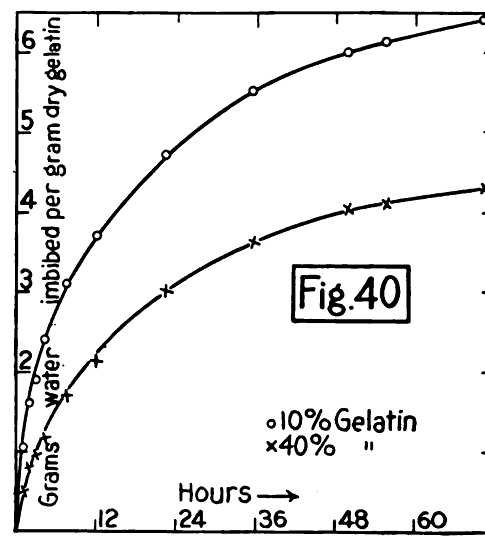
Figure 38 ([20]) shows the variation of γ with temperature for various gelatin solutions. A_1 = pure H_2O. A_2 = 5 g gelatin per 100 cc water solution. B = pure formamide (same for 5 g gelatin per 100 cc formamide solution). C = phenol-acetic acid mixture (dotted line gives values of γ after addition of gelatin, 5 g per 100 cm^3 of mixture). D = *o*-cresol-acetic acid mixture (dotted line after addition of 5 g gelatin per 100 cm^3 of mixture). E_1 = pure acetic acid. E_2 = pure acetic acid + 5 g gelatin per 100 cm^3. The inset gives γ for water-alcohol solutions of gelatin against temperature. Solid curve for mixtures of alcohol-water. Dotted curve for mixtures with 10 g gelatin per 100 cm^3 solution.

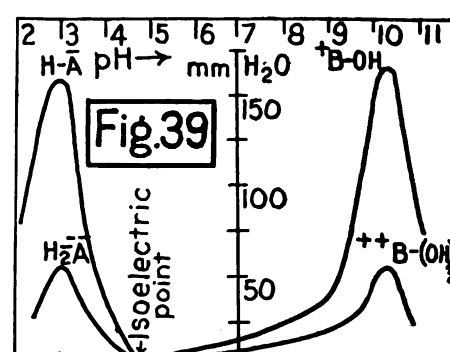


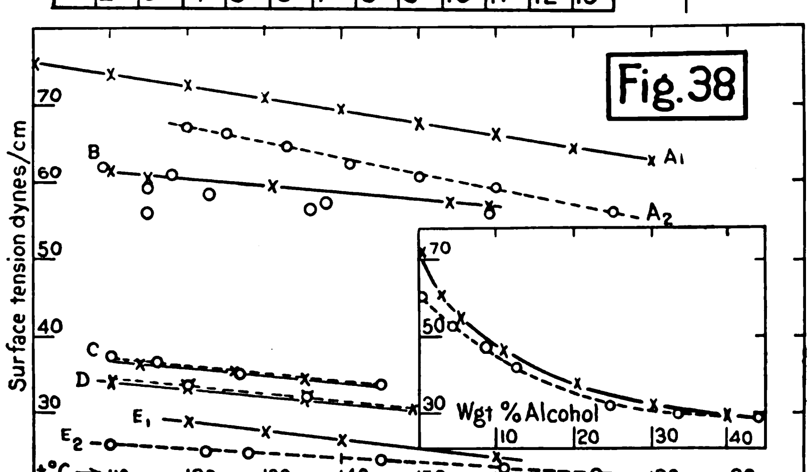


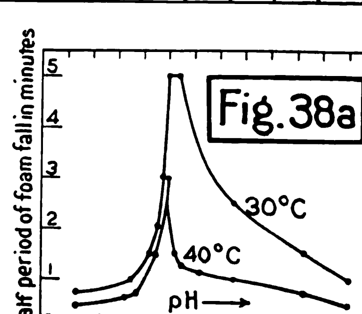
Two per cent gelatin solutions at 30°C by stalagmometer show a rise in γ to a maximum at pH = 8–9, falling to a minimum at pH = 4.5 and rising to a lower maximum at pH = 3 ([12]).

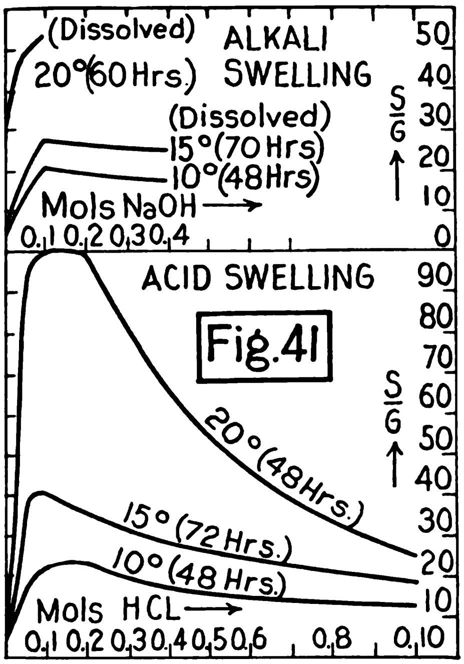


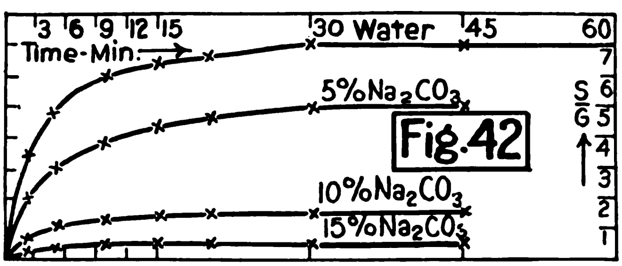


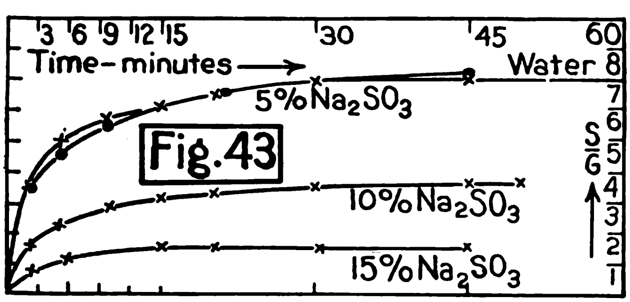


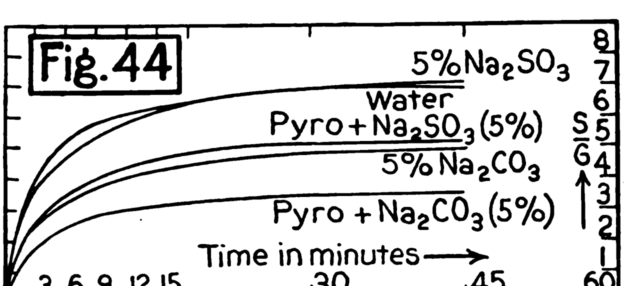












See (54) for γ between toluene and gelatin solutions.

Figure 38*a* shows the relation between pH and foam on aqueous gelatin solutions, γ for the solution being smallest at the isoelectric point where the foam is most stable.

Thermal Expansion

Aqueous solutions of gelatin (37)

Wt. % gelatin	0.0	2.02	5.04	8.9	10.4	16.5	24.8
$\frac{10^6}{V}\frac{\Delta V}{\Delta t}$ (15°–32°C)	241	249	267	289	300	341	386

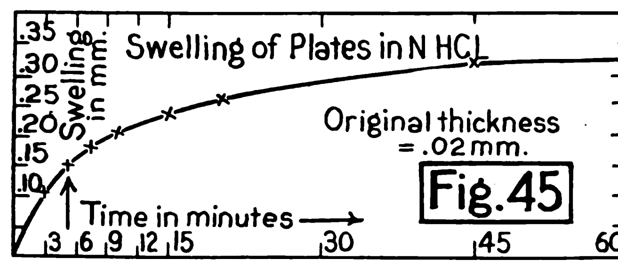
Wt. % gelatin	0.0	3.60	7.05	13.00
Temp. of max. density	+4.0°	+2.5°	+1.3°	−1.2°

Osmotic Pressure

Figure 39 gives the osmotic pressure at 10°C of 0.5 g gelatin per 100 cm³ water solution against solutions of acids and bases of pH value indicated (29).

Swelling and Contractility

Figure 40 shows the swelling behavior of dry gelatins when immersed in pure H_2O for the times indicated. The 10% gel was prepared by drying a solution made from 90 g H_2O + 10 g gelatin and the 40% gel from a solution of 60 g H_2O + 40 g gelatin, the dried pieces being of the same area and thickness (15).



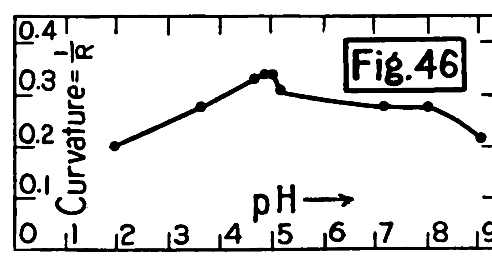


Figure 41 shows the influence of temperature, S/G = grams H_2O imbibed per gram gelatin (25).

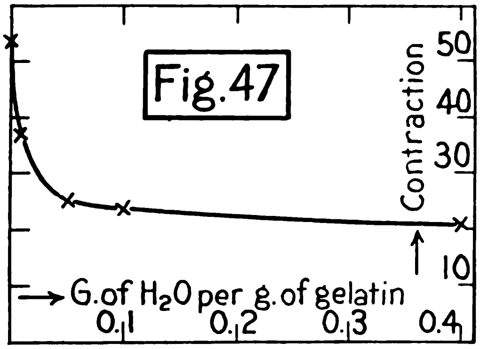
Figures 42, 43, 44, and 45. Silver bromide emulsion gelatin on plates when immersed in the solutions indicated for varying times (25).

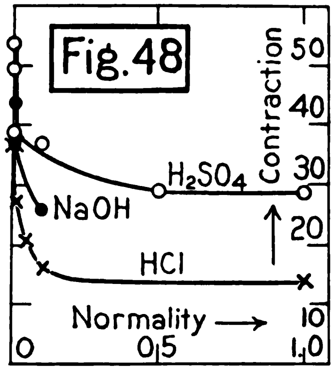
The following table and Fig. 46 show the contractility of gelatin films as measured by the curvature produced in thin Al discs coated on one side with 10% gelatin solution and dried under uniform conditions. In Fig. 46, the gelatin films were prepared from de-ashed material, in solutions of the pH indicated (26).

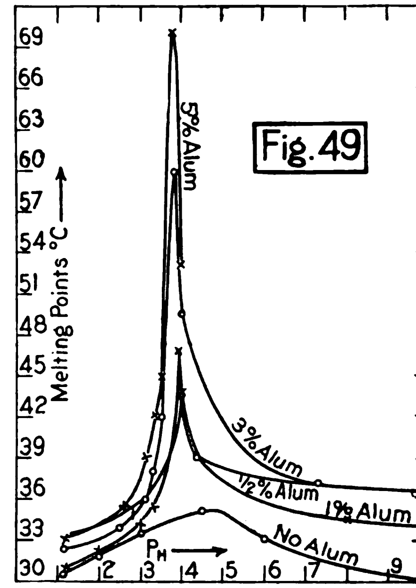
Contractility

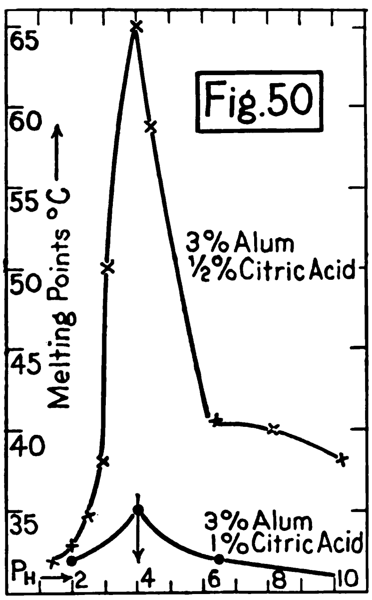
Gelatin	Radius in cm	Curvature 1/R	Remarks
Commercial hard A.	24	0.041	Good grade
Commercial hard B.	24.5	0.0405	photographic gelatins
Ossein gelatin	26	0.038	Photographic quality
Hide gelatin No. 6902	31	0.032	Good grade hide gelatin
Same, de-ashed	31	0.032	Ash less than 0.01%
Sizing gelatin	34	0.029	Poor grade

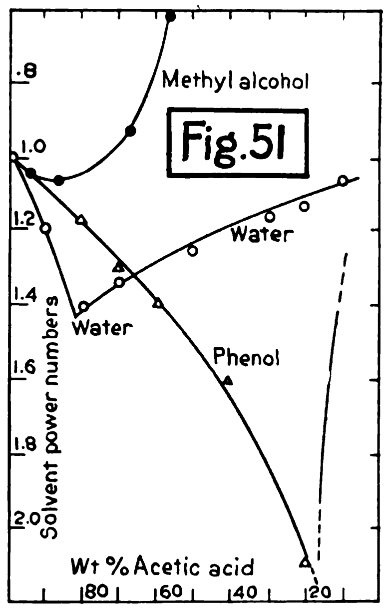
There is no definite relation between the contractility of gelatins and their swelling on immersion in H_2O, indicating that there are individual structural differences in gelatins, depending not simply on physico-chemical conditions but on origin and previous history (26).

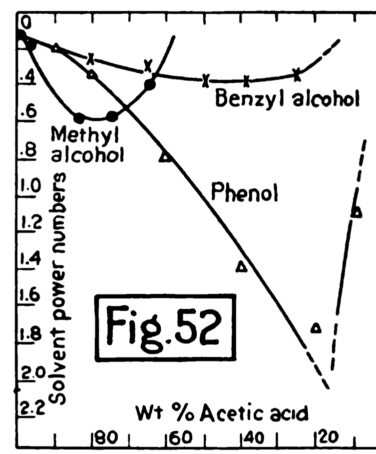


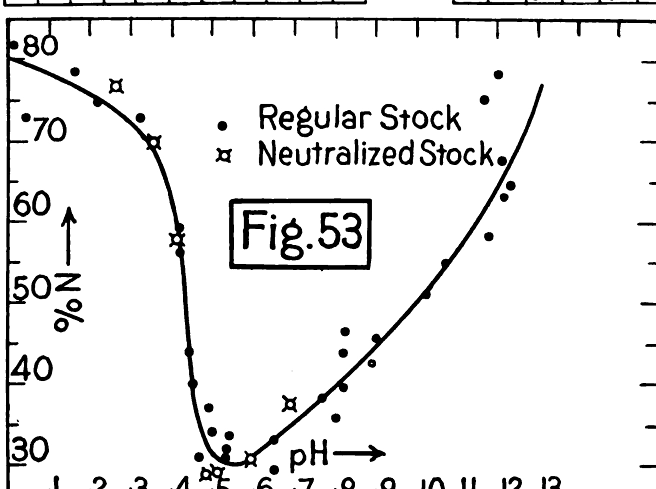








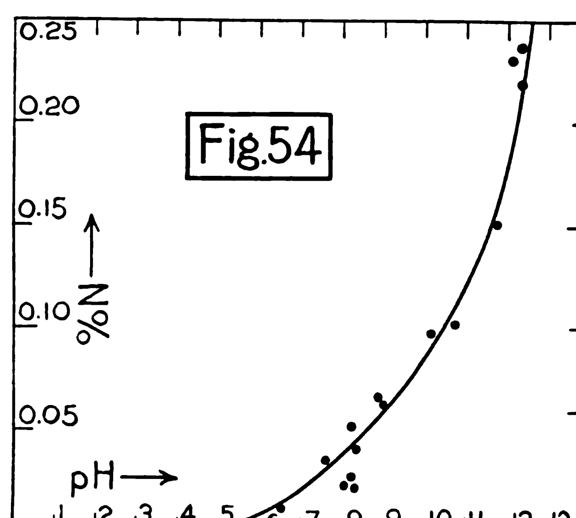




Gelatin shows two points of minimum swelling with change in pH, one at pH = 4.7 and the other at pH = 7.7 ([41]).

For the swelling of gelatin in solutions of polybasic acids and their salts, *see* ([42]).

Figure 47 shows the contraction in mm^3 per g of gelatin on dissolving in 100 cm^3 of H_2O as a function of the H_2O content of the gelatin before dissolving, and Fig. 48 shows the contraction on dissolving a gelatin of constant H_2O content in 100 cm^3 of acid or alkali of varying normality ([31]).



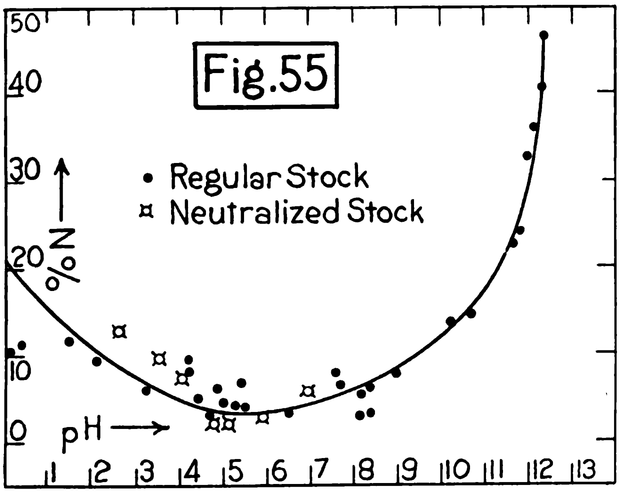
The swelling of gelatin gels shows a maximum at pH = 3–3.5 and a minimum at pH = 5 ([4]). For effects of certain solutes in increasing swelling *v.* ([36]).

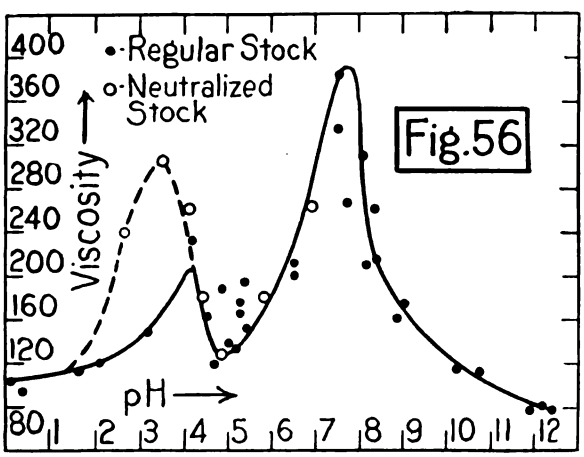
Gelatin gels show a minimum resistance to stretch at pH = 4.7 and a maximum at pH = 3 and 11 ([24]).

Melting Point

Figure 49 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions of the concentrations indicated ([25]).

Figure 50 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions with 0.5 and 1.0% of citric acid ([25]).





Solubility in H_2O

<0.01 wt. % at room temp. ([17, 18]).

Parts ‰. 22°C, 1; 18.3°, 0.7; 15–17°, 0.5; 0°, 0.2 ([35]).

Solvent Power Numbers

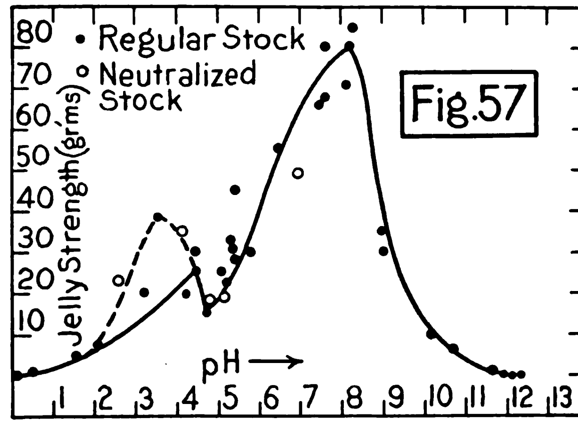
The solvent power number is the relative volume of a liquid required to start the precipitation of gelatin from a solution containing 15 g gelatin per 100 cm^3, upon mixing at 25°C.

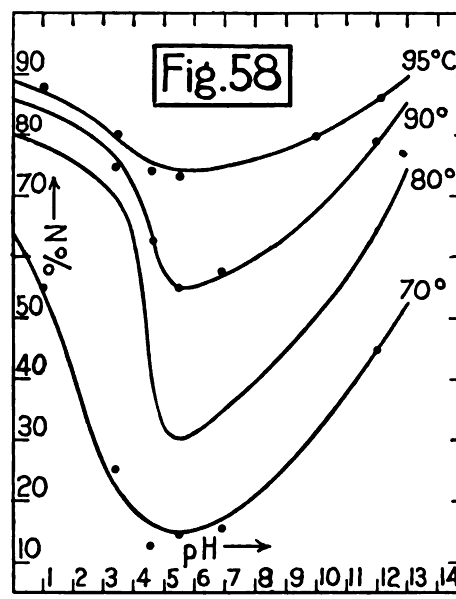
Figure 51 shows the solvent power numbers for acetone on solutions of gelatin in acetic acid mixtures and Fig. 52 the same values for xylene ([20]).

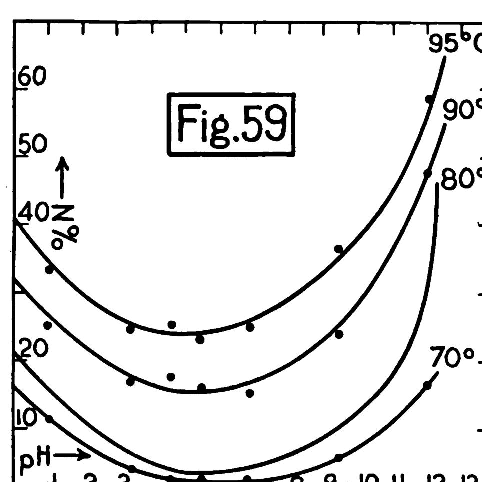
Hydrolysis of Collagen to Gelatin ([6])

The experiments covered by the following figs. were carried out on well limed hide pieces for periods of 8 hr unless otherwise indicated and exhibit the effect of the pH during hydrolyzing on the factors named:

Fig. 53. On the % of total N recovered in the solution.
Fig. 54. On the % of N evolved as NH_3.
Fig. 55. On the % of amino acid N recovered in the solution.
Fig. 56. On the viscosity (in arbitrary units) of the product at 35°C.
Fig. 57. On the jelly strength of the product at 10°C.
Fig. 58. On total N recovered in the solution after hydrolyzing at temperatures indicated.
Fig. 59. On amino acid N in the solution after hydrolyzing at temperatures indicated.
Fig. 60. On the total N recovered and Fig. 61 on the amino acid N, in the solution after hydrolyzing at 80°C for times indicated.







Mutarotation

The change in specific rotation (mutarotation) of gelatin solutions of constant concentration, upon reducing the temperature from 35° to 15°C, decreases very rapidly with decreasing jelly consistency of the gelatin or glue (4). *See also* (17, 35, 48).

Electrical Conductivity

The conductivity of gelatin solutions in water is a useful criterion of the purity of the gelatin. The purest solutions which have been prepared have the same conductivity as pure water (38).

See (39) for the conductivity of some gelatin and glutin solutions.

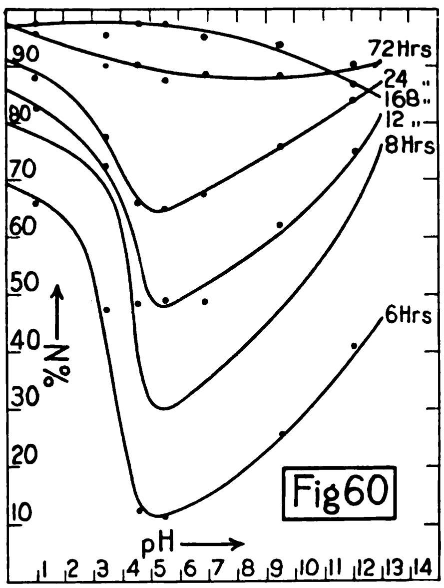


Fig 60

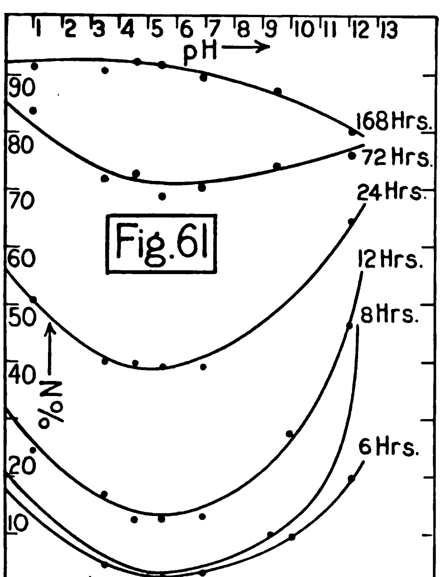


Fig. 61

Miscellaneous

For the extraction of gelatin from bones as a function of temperature and time, *see* (19).

Figure 62 shows the influence of pH on the alcohol number, turbidity, and foam of gelatin solutions (4).

A method of determining the gelling power of gelatins is given in (43).

For the liquefaction of gelatins by salt solutions, *see* (44).

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(For a key to the periodicals see end of volume)

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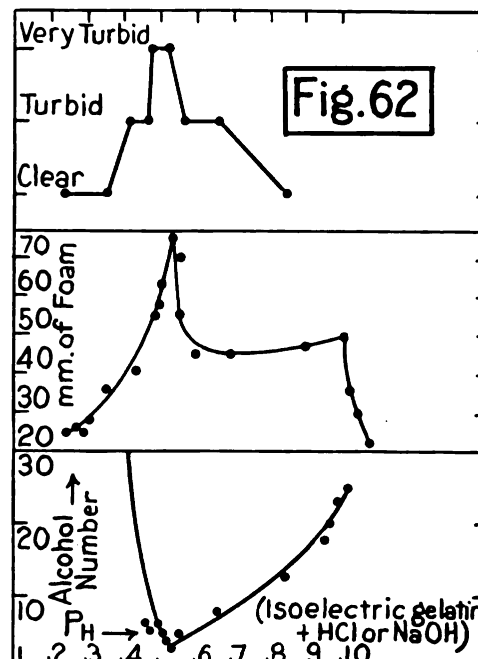

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TEXTILE FIBERS

J. Merritt Matthews

BOTANICAL CLASSIFICATION OF IMPORTANT VEGETABLE FIBERS

(A) Vegetable hairs.
1. Cotton (seed-hairs of *Gossypium* sp.).
2. Bombax cotton (fruit-hairs of *Bombaceæ*).
3. Vegetable silks (seed-hairs of various *Asclepiadaceæ* and *Apocynaceæ*).

(B) Bast fibers from the stalks and stems of dicotyledonous plants.

(a) Flax-like fibers.
4. Flax (*Linum usitatissimum*).
5. Hemp (*Cannabis sativa*).
6. Gambo hemp (*Hibiscus cannabinus*).
7. Sunn hemp (*Crotalaria juncea*).
8. Queensland hemp (*Sida retusa*).
9. Yercum fiber (*Calotropis gigantea*).

(b) Bœhmeria fibers.
10. Ramie or China grass (*Bœhmeria nivea*).

(c) Jute-like fibers.
11. Jute (*Corchorus capsularis* and *C. olitorius*).
12. Raibhenda (*Abelmoschus tetraphyllos*).
13. Pseudo-jute (*Urena sinuata*).

(d) Coarse bast fibers.
14. Bast fibers from *Bauhinia racemosa*.
15. Bast fibers from *Thespesia lampas*.
16. Bast fibers from *Cordia latifolia*.

(e) Basts.
17. Linden bast (*Tilia* sp.).
18. Bast from *Sterculia villosa*.
19. Bast from *Holoptelea integrifolia*.
20. Bast from *Kydia calycina*.
21. Bast from *Lasiosyphon speciosus*.
22. Bast from *Sponia Wightii*.

(C) Vascular bundles from monocotyledonous plants.

(a) Leaf fibers.
23. Manila hemp or abaca (*Musa textilis* and others of this kind).
24. Pita (*Agave americana* and *A. mexicana*).
25. Sisal (*Agave rigida*).
26. Mauritius hemp (*Agave fœtida*).
27. New Zealand flax (*Phormium tenax*).
28. Aloe fibers (*Aloë* sp.).
29. Bromelia fibers (*Bromelia* sp.).
30. Pandanus fibers (*Pandanus* sp.).
31. Sansevieria fibers (*Sansevieria* sp.).
32. Esparto fibers (*Stipa tenacissima*).
33. Piassave (*Attalea funifera*, *Raphia vinifera*, etc.).

(b) Stem fibers.
34. Tillandsia fibers, southern moss (*Tillandsia usneoides*).

(c) Fruit fibers.
35. Coir or coconut fiber (*Cocos nucifera*).
36. Peat fibers.

(d) Paper fibers.
37. Straw fibers (rye, wheat, oat, rice).
38. Esparto fibers (leaf fibers of *Stipa tenacissima*).
39. Bamboo fibers (*Bambusa* sp.).
40. Wood fiber (pine, fir, aspen, etc.).
41. Bast fiber from paper mulberry (*Broussonetia papyrifera*).
42. Bast fiber from *Edgeworthia papyrifera*.
43. Peat fibers.

(Wiesner, *Die Rohstoffe des Pflanzenreiches*)

MICROSCOPICAL CHARACTERISTICS OF IMPORTANT VEGETABLE FIBERS

Fiber	Microscopical appearance
Cotton	Appears as a flat, ribbon-like band, more or less twisted on its longitudinal axis. Twist of fiber not continuous in one direction; cell-walls thick; lumen breadth much thicker than cell-wall; between thickened edges fiber shows finely granulated surface. Diameter uniform for ¾ length, then tapers to a point where it is cylindrical and solid
Flax	Cylindrical tapering to sharp point; cell-wall so thick that lumen appears as thread; fine cross-lines at intervals give appearance of joints or nodes, sometimes intersecting like letter X
Hemp	Lumen is broad, equaling or exceeding the thickness of the walls. Pronounced longitudinal striations. Ends of fibers blunt and thick-walled, often with lateral branches. Dislocations or folds; also swellings and cross-fissures. Fibers less transparent than flax and canal more difficult to distinguish
Jute	Lumen irregular, at times as wide as or wider than cell-wall; at ends of fiber lumen broadens out; end round. Longitudinal striations, no transverse markings, no jointed ridges
Manila hemp (abaca)	Lumen broad, distinct and uniform; cell-wall thin; ends narrow and sharp; no markings; diameter uniform
Manila hemp, sisal or Domingo hemp.	Fibers usually very stiff, and become very broad toward middle; have broad lumen, broad, blunt, thick ends, which are seldom forked. Short thick-walled cells are abundant, and show a narrow lumen and distinct surface pores. Peculiar spiral and parenchyma cells are often present
Straw	Bast cells are long thin fibers of regular structure with small canal; very slender and taper to fine point. Epidermal cells are thick-walled, short, broad, serrated. Parenchyma cells thin-walled and shaped like coffee bean
Esparto	Cells smaller than, but very similar to, straw cellulose. Esparto does not have the thin-walled bean-shaped cells, but has very small characteristic pear-shaped cells. Bast cells have numerous cross-markings
Ramie	Bast cells very long and broad, diameter very irregular; base very irregular; lumen, sometimes quite distinct, and sometimes disappearing entirely; fibers show numerous joints and transverse fissures; ends of fibers form a thick-walled, rounded point, and the lumen is reduced to a line
New Zealand flax.	Fiber elements, or cells, are usually very regular and uniform, surface is smooth in general. Lumen is usually narrower than cell-wall and very uniform in width. Ends are sharply pointed, and not divided. Fragments of parenchyma and epidermis can often be seen on the fibers
Pita fiber	Fiber is stiff and short, has a rather thin wall. Fiber has a distinctive wavy appearance and is very elastic. Very similar to sisal hemp in microscopical appearance
Pineapple leaf fiber.	Fiber very fine and has great durability. Lumen narrow and appears like a line. This fiber is distinguished from all other leaf fibers by its extreme fineness
Coniferous wood fibers.	Fibers from coniferous trees have a characteristic flat ribbon-like appearance, and numerous circular spots or pores are to be seen on many of them. The circular markings are more prominent in hard, strong sulfites or sulfates, but are often less distinct in well-boiled pulps. Occasionally the cells are twisted something like cotton fibers. The shape and distribution of the pores in the fibers give some indication of the tree used
Broad-leaf hardwood fibers.	The fibers from broad-leaf trees are shorter and more cylindrical in shape, and are always pointed at each end, and occasionally exhibit cross-markings. In addition to the true fibers, there are always a number of vessels, tubular in shape, short and of very large diameter, which show numerous pits; these establish the presence of fibers from broad-leaf trees

DIMENSIONS OF FIBER ELEMENTS

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
Abelmoschus tetraphyllos	0.1	1.6		8	29	13	W
Agave americana (pita)	1.0	2.2		16	21	17	W
	1.5	4	2.5	20	32	24	V
Aloë perfoliata	1.3	3.7		15	24		W
Asclepias (vegetable silk)	10	30		20	44		W
Bauhinia racemosa	1.5	4.0		8	20		W
Beaumontia (vegetable silk)	30	45		33	50		W
Boehmeria nivea (China grass)			22.0	40	80	50	W
Boehmeria tenacissima (ramie)			8.0	16	12.6		W
Bombax heptaphyllum (cotton wool)	20	30		19	29		W
Bromelia karatas (silk grass)	1.4	6.7		27	42		W
	2.5	10	5	20	32	24	V
Bromelia pinguin (wild pineapple)	0.8	2.5	2	8	16	13	V
Calotropis gigantea (bast)	0.7	3.0		18	25		W
Calotropis gigantea (vegetable silk)	20	30		12	42	38	W
Cannabis sativa (hemp)	0.8	4.1		16	32	20	W
	5	55	20	16	50	22	V
Cocos nucifera (coir fiber)	0.4	0.9		12	20	16	W
	0.4	1	0.7	12	24	20	V
Corchorus capsularis (jute)	0.8	4.1		10	21	16	W
	1.5	5	2	20	25	22.5	V
Corchorus olitorius (jute)	0.8	4.1		16	32	20	W
Cordia latifolia	0.1	1.6		14.7	16.8	15	W
Corypha umbraculifera (talipot palm)	1.5	5	3	16	28	24	V
Crotalaria juncea (sunn hemp)	0.5	6.9		20	42		W
	4	12	8	25	50	30	V
Elaeis guineensis	1.5	3.5	2.5	10	13	11	V
Esparto grass	1.5	1.9		9	15		W
	0.5	3.5	1.5	7	18	12	V
Gossypium acuminatum (cotton)			28.4	20.1	29.9	29.4	W
Gossypium arboreum (cotton)			25.0	20	37.8	29.9	W
Gossypium barbadense (cotton)			40.5	19.2	27.9	25.2	W
Gossypium conglomeratum (cotton)			35.1	17	27.1	25.9	W
Gossypium herbaceum (cotton). *See also* following table			18.2	11.9	22	18.5	W
Hibiscus cannabinus (gambo hemp)	2	6	5	14	33	21	V
	4.0	12.0		20	41		W
Holoptelea integrifolia	0.9	2.1		9	14	12	W
Humulus lupulus (hop)	4	19	10	12	26	16	V
Kydia calycina	1	2		17	24		W
Lagetta lintearia (lace bark)	3	6	5	10	20		V
Lasiosyphon speciosus	0.4	5.1		8	29		W
Linen	4	66	25	15	37	20	V
Linum usitatissimum (flax)	2.0	4.0		12	25	16	W
Lygaeum spartum	1.3	4.5	2.5	12	20	15	V

DIMENSIONS OF FIBER ELEMENTS.—(*Continued*)

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
Marsdenia (vegetable silk)	10	25		19	33		W
Mauritia flexuosa (ita palm)	1	3	1.5	10	16	12	V
Melilotus alba (sweet clover)	5	18	10	20	36	30	V
Musa paradisaica (banana)			5	20	40	28	V
Musa textilis (Manila)	3	12	6	16	32	24	V
Pandanus odoratissimus	1.0	4.2				20	W
Paper mulberry		25	10			30	V
Phoenix dactylifera (date palm)	2	6	3	16	24	20	V
Phormium tenax (New Zealand flax)	2.5	5.6		8	29	13	W
	5	15	9	10	20	16	V
Pineapple	3	9	5	4	8	6	V
Raphia toedigera	1.5	3	2.5	12	20	16	V
Salix alba (willow)		3	2	17	30	22	V
Sansevieria	1.5	6	3	15	26	20	V
Sarothamnus vulgaris (broom-grass)	2	9	5	10	25	15	V
Sida retusa	0.8	2.3		15	25		W
Spartium junceum (feather-grass)	5	16	10			20	V
Sponia Wightii			4			21	W
Sterculia villosa	1.5	3.5		17	25	20	W
Strophanthus (vegetable silk)	10	56		49	92		W
Thespesia lampas	0.9	4.7		12	21	16	W
Tilia europaea (linden-bast)	1.2	5	2	14	20	16	V
	1.1	2.6				15	W
Tillandsia	0.2	0.5		6	15		W
Urena sinuata	1.1	3.2		9	24	15	W
Urtica dioica (nettle)	4	57	27	20	70	50	V
Urtica nivea (ramie) *See also Boehmeria*	60	250	120		80	50	V
Yucca	0.5	6	4	10	20	15	V

V = Vétillard, *Études sur les fibres végétales textiles.* W = Wiesner, *Die Rohstoffe des Pflanzenreiches.*

COTTON

DIMENSIONS OF COTTON FIBERS

	Length, mm			Diameter, microns
	Max.	Min.	Av.	
African	30.2	22.1	26.2	20.8
Algerian			37.5	
Brazilian				
Ceara	30.2	22.1	26.2	20.1
Maceo			29.3	
Maranham	30.2	23.9	26.9	20.1
Paraiba			29.7	
Pernambuco	34.8	28.4	31.8	20.1
Surinam			30.2	
American				
Georgia			25.4	10.3
Louisiana			25.0	
Mississippi			24.2	13.4
Mobile	25.4	19.1	22.1	19.4
Orleans	28.4	23.9	26.2	19.2
Tennessee			25.1	15.0
Texas	28.4	22.1	25.4	19.4
Upland	26.9	20.6	23.9	19.4
Chinese			21.4	24.1
Egyptian				
Brown	38.1	28.4	33.3	18.7
Gallini	42.4	31.7	36.3	17.1
Smyrna	28.4	22.1	25.4	22.8
White	34.8	28.4	31.7	19.5
Indian				
Bengal	25.4	19.1	22.1	22.1
Broach	25.4	17.5	21.3	21.1
Comptah	25.4	19.1	22.1	21.5
Dharwar	22.6	17.5	22.1	21.1
Dhollerah	26.9	21.3	22.6	21.5
Hingunghat	30.2	22.1	26.2	21.1

DIMENSIONS OF COTTON FIBERS.—(*Continued*)

	Length, mm			Diameter, microns
	Max.	Min.	Av.	
Madras	25.4	19.1	22.1	21.1
Oomrawutte	26.9	19.1	21.9	21.5
Scinde	22.1	12.7	16.5	21.3
Tinnevelly	26.9	17.5	22.1	21.1
Peruvian				
Rough	36.6	23.5	32.5	19.8
Smooth	36.6	23.5	32.5	19.5
Sea Island				
Edisto			41.9	9.65
Fiji	53.8	42.4	46.6	16.2
Fitschi			48.7	16.7
Florida	45.9	38.1	41.9	16.2
John Isle			39.3	
Peruvian	44.5	34.8	39.6	17.1
Tahiti	44.5	31.7	38.1	16.3
Wodomalam			39.0	
West Indian	34.8	26.9	31.0	22.8

Physical Properties of Individual Cotton Fibers

Variety	Length, cm	Rigidity, dynes cm^2	Weight, 10^{-6} g
Sea-island	4.2–5	0.010–0.021	5.9–6.7
Egyptian nubarri	3.6	0.024	6.3
Egyptian affifi	3.1	0.032	5.6
Peruvian hybrid	2.9	0.063	7.7
Trinidad native	2.6	0.045	4.9
Upland Memphis	2.6	0.039	5.3
American FGM	2.4	0.061	5.6
Upland cross	2.3	0.045	5.0
Pernams	2.2	0.071	6.7
Indian Bharat	1.7	0.111	5.8

The rigidity of the fiber is the torque, or twisting force, in the fiber when 1 cm is given one complete twist.

Pierce[1] furnishes the following physical factors for the cotton fiber, that may be calculated approximately from the staple length:

Staple length	L (in cm)
Fiber mass	5.8×10^{-6} g
Mass per centimeter	$(5.8/L) \times 10^{-6}$ g
Wall cross section	$(3.9/L) \times 10^{-6}$ cm^2
Rigidity	$0.3/L^2$ dynes cm^2
Breaking load	$20/L$ g
Fibers in yarn section	$1000L/N$ or $(L''/4N) \times 10^4$
Initial couple in yarn	$300t/LN = 300p/L\sqrt{N}$

The density of the cotton fiber is assumed as 1.51; N is the count of the yarn, L'' is the staple length in inches, t is the twist, and p the spinning factor $t/\sqrt{N}$.

BREAKING STRENGTHS OF DIFFERENT VARIETIES OF COTTON

Cotton	Mean breaking strain	
	Grains	Grams
Sea-island (Edisto)	83.9	5.45
Queensland	147.6	9.59
Egyptian	127.2	7.26
Maranham	107.1	6.96
Bengal	100.6	6.53
Pernambuco	140.2	9.11
New Orleans	147.7	9.61
Upland	104.5	6.79
Surat (Dhollerah)	141.9	9.22
Surat (Comptah)	163.7	10.64

[1] *415*, **14**: 7; 23.

Absorption of Sodium Hydroxide by Cotton[1]

Concn. NaOH, g per 100 cc H_2O	0.4	2.0	6.0	8.0	12	16	20	24	28	33	35	40
g NaOH fixed per 100 g cotton	0.4	0.9	2.7	4.4	8.4	12.6	13	13	15.4	20.4	22.5	22.5

[1] Vieweg, *25*, **40**: 3876; 07.

Effect of Mercerizing on the Physical Properties of Cotton Yarns

Thoms[1] obtained the following results on the effect of mercerizing and bleaching on cotton yarns:

	Gray	Boiled	Mercerized	Mercerized and bleached, chloride of lime
Loss in weight, %	0	5.53	4.61	3.02
Loss in length, %	0	1.95	1.00	0.37
Mean count	16.46	17.66	17.42	17.35
Lea break, in lb	97.0	72.41	82.19	86.41
Double thread break, in oz	27.68	23.26	26.12	27.55
Double thread stretch, in $\frac{1}{8}$ in	20.57	14.22	11.08	10.25
Mean turns per in	20.18	19.88	19.57	19.99
Moisture, % as regain	5.86	5.07	7.18	7.34

	Mercerized and bleached, sodium hypochlorite	Mercerized and bleached, electrolytic bleach	Bleached, chloride of lime	Bleached, sodium hypochlorite
Loss in weight, %	3.03	3.06	5.00	4.91
Loss in length, %	1.11	1.14	2.04	1.73
Mean count	17.02	17.02	17.35	17.45
Lea break, in lb	87.12	85.94	17.66	79.97
Double thread break, in oz	28.08	27.58	24.14	23.93
Double thread stretch, in $\frac{1}{8}$ in	11.09	10.78	13.76	13.97
Mean turns per in	20.20	20.25	20.07	20.11
Moisture, % as regain	7.55	7.59	5.28	5.46

	Bleached, electrolytic bleach	Bleached, chloride of lime and mercerized	Bleached, sodium hypochlorite and mercerized	Bleached, electrolytic bleach and mercerized
Loss in weight, %	4.88	3.40	3.37	3.37
Loss in length, %	1.97	0.17	0.63	0.10 gain
Mean count	17.40	17.58	17.24	17.40
Lea break, in lb	79.78	80.28	80.47	78.28
Double thread break, in oz	23.65	26.52	26.14	25.85
Double thread stretch, in $\frac{1}{8}$ in	13.78	9.08	9.23	8.90
Mean turns per in	19.89	19.91	19.32	19.59
Moisture, % as regain	5.42	7.63	7.69	8.19

[1] *290*, **27**: 178; 11.

SILK

Sizes of Cocoon Threads from Different Sources[1]

Source	Size in deniers
Yellow Piedmont	3.06
Yellow Cevennes	3.03
White Persians	2.87
Yellow Adrianople	2.84
Yellow Tuscan	2.81
Yellow Salonika	2.73
Yellow Greece	2.61
Yellow Hungarian	2.64
White Turkestan	2.68
White Japanese	2.12
White Chinese	1.96

[1] Report Lyon's Conditioning House.

The single silk filament in the double cocoon thread, therefore, is about 1¼ to 1½ deniers in size.

Comparison of Different Varieties of Silk Fibers[1]

Name of silk	Country	Diameter, in.		Elasticity, in. in 1 ft.		Tensile strength, dr		Size of cocoon, in.
		Outer fibers	Inner fibers	Outer fibers	Inner fibers	Outer fibers	Inner fibers	
Bombyx mori	China	0.00052	0.00071	1.3	1.9	1.6	2.6	1.1×0.5
Bombyx mori	Italy	0.00053	0.00068	1.2	1.9	1.9	2.6	1.2×0.6
Bombyx mori	Japan	0.00057	0.00069	1.2	1.4	2.0	3.1	1.1×0.6
Bombyx fortunatus	Bengal	0.00045	0.00051	1.8	2.3	1.6	2.8	1.2×0.5
Bombyx textor	India	0.00042	0.00047	1.5	1.9	1.4	2.6	1.2×1.5
Antheræa mylitta	India	0.00161	0.00172	1.9	2.7	6.6	7.8	1.5×0.8
Attacus ricini	India	0.00085	0.00093	1.7	2.0	1.5	3.0	1.5×0.8
Attacus cynthia	India	0.00083	0.00097	2.6	2.9	2.4	3.5	1.8×0.8
Antheræa assama	India	0.00128	0.00125	2.4	2.9	2.8	4.8	1.8×1.0
Attacus selene	India	0.00100	0.00109	2.0	2.8	2.4	4.0	3.0×1.2
Attacus atlas	India	0.00102	0.00111	1.9	2.8	2.1	4.1	3.5×0.8
Antheræa yamamai	Japan	0.00088	0.00096	2.0	4.0	6.8	7.5	1.5×0.8
Cricula trifenestrata	India		0.00120					2.0×0.8
Antheræa pernyi	China	0.00118	0.00138	2.0	2.7	3.2	5.8	1.6×0.8

[1] Murphy, *Textile Industries*, p. 6.

Tensile Strength

	kg/mm²	
	Dry	Wet
Chinese silk	53.2	46.7
French raw silk	50.4	40.9
French silk, boiled off	25.5	13.6
French silk, dyed red and weighted	20.0	15.6
French silk, blue-black, weighted 110 %	12.1	8.0
French silk, black, weighted 140 %	7.9	6.3
French silk, black, weighted 500 %	2.2	

RAYONS OR ARTIFICIAL SILKS

Physical Properties

Type	Breaking strain per denier in g	Elasticity, %
Natural silk	2.50	21.6
Chardonnet	0.93	8.0
Lehner	1.43	7.5
Cuprammonium	1.64	12.5
Gelatin	0.63	3.8
Viscose	1.40	9.5

BREAKING STRENGTH

Type	kg/mm² Dry	kg/mm² Wet
Chardonnet's collodion, undyed	14.7	1.7
Lenher's collodion, undyed	17.1	4.3
Strehlenert's collodion, undyed	15.9	3.6
Cuprammonium, undyed	19.1	3.2
Viscose early samples	11.4	3.5
Viscose latest samples	21.5	
Cotton yarn (for comparison)	11.5	18.6

Type	Tensile strength per denier in g, Dry	Tensile strength per denier in g, Wet	Elasticity, %
Viscose	1.3–1.8	0.4–0.8	15
Acetate	1.3–1.4	1.5	20
Cuprammonium	1.4	0.55	16

WOOL

EFFECT OF MOISTURE CONTENT ON STRENGTH[1]

Treatment	Average strength of warp strips, lb.	Average elongation before rupture, in.	Moisture content, %
Before treatment	160.0	2.26	10.04
After wetting	130.7	4.53	53.0
Damp	123.6	4.46	33.0
Air-dry	156.3	2.67	10.54

[1] Woodmansey, *290*, **1918**, 227.

BREAKING STRENGTH[1]

Kind of wool	Strength in g High	Low	Average
Cotswold	44.54	16.10	30.44
Leicester	30.00	15.50	23.70
Lincoln	36.72	15.79	25.66
Southdown	21.29	6.48	12.78
Oxford	45.15	19.15	30.43
Merino	11.92	3.86	7.35

[1] McMurtie, *Reports on the examination of wool fibers*.

ACTION OF CAUSTIC SODA ON BREAKING STRENGTH

NaOH solution, °Bé	Breaking strength, g	NaOH solution, °Bé	Breaking strength, g
Untreated wool	610	32	420
4	510	36	580
8	475	40	770
12	250	42	815
16	180	44	740
20	95	48	720
24	200	50	620
28	240		

ABSORPTION OF VARIOUS ACIDS[1]

% acid used	Hydrochloric acid Absorbed, %	Hydrochloric acid Permanently retained, %	Sulfuric acid Absorbed, %	Sulfuric acid Permanently retained, %	Oxalic acid Absorbed, %	Oxalic acid Permanently retained, %	Acetic acid Absorbed, %	Acetic acid Permanently retained, %	Formic acid Absorbed, %	Formic acid Permanently retained, %
1	0.97	0.63	0.97	0.78	0.94	0.72	0.73	0.63	0.33	0.15
2	1.51	0.58	1.90	1.48	1.72	0.95	0.94	0.73	0.71	0.34
3	1.97	0.71	2.67	1.76	2.46	0.94	0.97	0.72	0.95	0.54
4	2.32	0.78	3.58	2.12	3.16	1.33	0.35	1.06	1.35	0.83
5	2.25	0.61	3.48	1.97	3.62	1.51	1.27	0.91	1.51	0.86
6	2.40	0.72	3.86	1.90	4.06	1.31	1.19	0.83	1.78	1.16
7	2.47	0.63	3.72	2.09	4.67	1.53	1.09	0.68	1.58	0.64
8	2.71	0.76	3.80	2.04	5.16	1.78	1.25	0.70	1.55	0.65
9	2.40	0.51	3.62	1.92	5.03	1.53	1.30	0.68	1.71	0.71
10	2.58	0.61	3.79	2.00	5.16	1.39	1.39	0.73	1.48	0.55
11	2.81	0.74	4.17	2.23	5.61	1.71	1.41	0.78	1.81	0.65
12	2.69	0.61	4.06	2.03	5.77	1.47	1.40	0.64	1.54	0.56

[1] Fort and Lloyd, *290*, **1914**, 5.

CORDAGE FIBERS

RELATIVE STRENGTHS

Fiber	Breaking strain of thread in g	Calculated cross section in mm²	Breaking strain, g per mm²	Breaking strain, tons per in.²	Breaking length, km
Sisal	1375	0.0240	57 300	36.2	38.2
Sansevieria	1289	0.0224	57 540	36.6	38.4
Manila (abaca)	1655	0.0181	91 430	58.0	60.9
Hedychium	828	0.0093	89 300	56.7	59.1
Cotton fiber	8.2	0.00026	31 458	20.0	22.8
Cellulose monofil	294	0.0140	21 000	13.3	14.0
Strong paper					10.0

MINOR HAIR FIBERS[1]

	Mohair	Alpaca	Camel-hair	Cashmere
Length, in.	9	12	5	3
Strength	Very strong	Fairly strong	Fairly strong	Fairly strong
Luster	Very high	High	Good	Good
Color	White	Vari-colored	Brownish	Brown and white
Fineness, in.	1/700	1/800	1/800	1/12 000
Handle	Fairly soft	Soft	Soft	Very soft
Form of staple	Straight	Straight	Fairly curly	Fairly curly
Uniformity	Uniform	Uniform	Fair	Fair
Uses	Dress fabrics, linings, upholsteries	Dress fabrics, linings	Dress fabrics	Shawls and hosiery

[1] Barker, *Textile Mfr.*

The "breaking length" refers to a length of fiber or thread that will break of its own weight.

PHYSICAL PROPERTIES[1]

Fiber	Weight per yd., gr	Breaking strain per strand, g	Breaking length in yd.
Abaca (Manila hemp), *Musa textilis:*			
Highest	0.567	46.6	82.2
Lowest	0.962	31.0	32.2
Average	0.772	34.8	45.0
Henequen (Yucatan sisal), *Agave fourcroya*	0.765	16.7	21.8
Sisal (Hawaii and East Africa), *Agave sisalana*	0.616	22.7	38.4
Cantalà (Manila maguey), *Agave cantala*	0.429	9.6	22.3
Phormium (New Zealand hemp), *Phormium tenax*	0.659	18.8	28.5
Zapupe Vincent (*Agave lespinassei*)	0.722	21.5	29.7
Cabuya (from Costa Rica), *Furcraea cabuya*	0.574	20.0	32.2

[1] Bureau of Plant Industry, Washington, D. C.

Comparative Strengths

The following results were from tests made on ropes of the same size and 1.2 m in length[1]:

COMPARATIVE STRENGTHS, DRY AND WET

Fiber	Dry, kg	Wet, kg
Hemp from Calcutta	72	86
Sunn hemp (fresh retted)	51	72
Sunn hemp (retted after drying)	27	35
Jute (*Corchorus capsularis*)	65	66
Jute (*Corchorus olitorius*)	51	56
Jute (*Corchorus strictus*)	47	52
Gambo hemp (*Hibiscus cannabinus*)	52	60
Roselle hemp (*Hibiscus sabdariffa*)	41	53
Hibiscus abelmoschus	49	49
Ramie (*Bœhmeria tenacissima*)	110	126

[1] Royle, *Fibrous Plants of India.*

COMPARATIVE STRENGTHS OF PREPARED ROPES, AND OF ROPES AFTER STEEPING IN WATER 116 DAYS

Fiber	Prepared ropes			Water-soaked, natural
	Natural	Tanned	Tarred	
Hemp, English	47			Rotted
Hemp, Calcutta	34	63	20	Rotted
Coir	39			24
Sunn hemp	31	31	27	Rotted
Jute	31	31	28	18
Linen, Calcutta	17			Rotted
Agave americana	50	36	35	Rotted
Sansevieria zeylanica	54	33	22	13

OKRA, JUTE AND OTHER CORDAGE FIBERS

	Breaking strain, lb.	
	Dry	Wet
Indian okra	79	95
Jute	113	125
Hemp (Bengal)	158	190
Hibiscus cannabinus	115	133
Hibiscus sabdariffa	95	117
Hibiscus strictus	104	115
Hibiscus furcatus	89	92

FUR FIBERS[1]

RELATIVE DURABILITY

Species	Durability (otter = 100)
Beaver	90
Bear, black or brown	94
Chinchilla	15
Ermine	25
Fox, natural	40
Fox, dyed	20–25
Goat	15
Hare	5
Kolinsky	25
Leopard	75
Lynx	25
Marten (skunk)	70
Mink, natural	70
Mink, dyed	35
Mole	7
Muskrat	45
Nutria (Coypu rat), plucked	25
Otter, sea	100
Otter, inland	100
Opossum	37
Rabbit	5
Raccoon, natural	65
Racoon, dyed	50
Sable	60
Seal, hair	80
Seal, fur	80
Squirrel, gray	20–25
Wolf	50
Wolverene	100

[1] Peterson, *The Fur Trade and Fur Bearing Animals.*

COMPARATIVE BREAKING STRENGTHS

Fiber	Breaking length in km	Breaking strength, kg per mm²
Cotton	25.0	37.6
Wool	8.3	10.9
Raw silk	33.0	44.8
Flax fibers	24.0	35.2
Jute	20.0	28.7
Ramie	20.0	28.7
Hemp	30.0	45.0
Manila hemp	31.8	47.7
Coconut fiber	17.8	29.2
Vegetable silk	24.5	35.9

	Ramie	Hemp	Flax	Silk	Cotton
Tensile strength	100	36	25	13	12
Elasticity	100	75	66	400	100
Torsion	100	95	80	600	400

TENSILE STRENGTHS OF FIBERS FOR EQUAL CROSS SECTIONS

Kind of fiber	Relative strength
Human hair	100
Lincoln wool	96.4
Leicester	119.9
Northumberland	130.9
Southdown	62.3
Australian merino	122.8

Tensile Strengths of Fibers for Equal Cross Sections.—(*Continued*)

Kind of fiber	Relative strength
Saxony merino	224.6
Mohair	136.2
Alpaca	358.5
Cotton, Egyptian	201.8

Comparative Strengths of Equivalent Yarns

Kind of yarn	Breaking strain, in oz.	
	1-in. test	27-in. test
Tram silk	45.0	40.0
Ramie	34.5	24.5
Linen	29.5	18.0
American cotton	17.0	13.5
Viscose rayon	11.0	11.0
Luster worsted	9.0	5.0
Botany worsted	7.5	3.5

SPECIFIC GRAVITIES

Determined in benzene (Vignon)

Silk, raw	1.30 to 1.37
Silk, boiled-off	1.25
Wool	1.28 to 1.33
Cotton	1.50 to 1.55
Mohair	1.30
Hemp	1.48
Ramie	1.51 to 1.52
Linen	1.50
Jute	1.48

SPECIFIC HEAT

The specific heat of all vegetable textile fibers thus far tested is practically that of cellulose, 0.32;[1] wool, 0.325; silk, 0.33; asbestos, 0.25; glass wool, 0.157.

[1] Limits observed by Dietz, *Leipzig Monatsch. Textilind.*, **1912**: 85, 0.319–0.327.

HYGROSCOPIC MOISTURE

Vegetable Fibers[1]

Fiber	Air-dry condition, %	Maximum amount hygroscopic water, %
Cotton	6.66	20.99
Flax (Belgian)	5.70	13.90
Jute	6.00	23.30
China-grass	6.52	18.15
Manila hemp (abaca)	12.50	50.00
Sunn hemp	5.31	10.87
Hibiscus cannabinus	7.38	14.61
Abelmoschus tetraphyllos	6.80	13.00
Esparto	6.95	13.32
Urena sinuata	7.02	15.20
Piassave	9.26	16.98
Sida retusa	7.49	17.11
Aloë perfoliata	6.95	18.03
Bromelia karatas	6.82	18.19
Thespesia lampas	10.83	18.19
Cordia latifolia	8.93	18.22
Bauhinia racemosa	7.84	19.12
Tillandsia fiber	9.00	20.50
Pita	12.30	30.00
Calotropis gigantea (bast)	5.67	13.13

[1] Wiesner, *Die Rohstoffe des Pflanzenreiches.*

Cotton and Mercerized Cotton[1]

	%
Ordinary cotton, unbleached	6.52
Ordinary cotton, bleached	6.25
Mercerized without tension, unbleached	9.33
Mercerized without tension, bleached	9.12
Mercerized with tension, unbleached	8.28
Mercerized with tension, bleached	8.05

[1] Higgins, *54*, **28**: 188; 09.

Moisture Fixed by Various Fibers at 100°C in an Atmosphere Saturated with Steam

Fiber, previously dried at 100°C	Water fixed, %
Bleached white cotton	23.0
Unbleached linen	27.7
Unbleached jute	28.4
Bleached silk	36.5
Bleached and mordanted wool	50.0

(Scheurer, *Bull. Soc. Ind. Mulh.*, **1900**: 89.)

Moisture Absorbed by Various Fibers at 75°F under Different Conditions of Humidity

Relative humidity, %	Moisture, %			Relative humidity, %	Moisture, %		
	Cotton	Silk	Wool		Cotton	Silk	Wool
5	1.4	1.8	2.2	55	6.3	9.4	13.4
10	2.4	3.2	4.0	60	6.7	9.9	14.2
15	3.0	4.4	5.7	65	7.3	10.5	15.0
20	3.6	5.4	7.1	70	7.9	11.4	16.0
25	3.9	6.1	8.3	75	8.8	12.5	17.1
30	4.3	6.7	9.4	80	9.9	14.0	18.6
35	4.6	7.3	10.4	85	11.4	15.9	20.5
40	5.0	7.8	11.0	90	13.6	18.4	23.2
45	5.3	8.4	11.8	95	17.5	22.7	27.0
50	5.7	8.8	12.6				

See also pp. 316, 323.

EFFECT OF HUMIDITY

Effect of Humidity on the Tensile Strength of Fabrics of Cotton, Linen and Wool

Humidity, %	Tensile strength in kg		
	Cotton	Linen	Wool
44	236	272	84.5
44	237	278	82.7
47	244	284	82.2
56	240	296	81.8
56	246	297	79.5
57	248	295	78.6
59	245.5	295	79.0
60	241	295	79.5
62	250	303	79.5
65	251	310	77.0
66	256	312	78.6
68	250.5	300.5	78.6
70	260	319	72.5
71	257.5	324	78.6
72	252	310.5	77.0
72	258	312.5	76.2
75	265	323	76.2
77	264.5	323	75.0
82	268	330	75.8
82	269	330.5	72.7

(Marschik and Breiner, *Leipz. Monatsch. Textilind.*, **1913**: 219.)

Tensile Strengths of Worsted Yarns at Different Relative Humidities

Relative humidity at 70°F, %	Tensile strength, g
45	234
55	231
65	220
75	216
85	191

Effect of Moisture on Strength of Linen Sail Cloth[1]

Moisture, %	Strength, kg	Moisture, %	Strength, kg
0.0	180	12.0	350
2.2	190	15.0	402
5.5	232	19.1	417
9.0	288	35.0	425

[1] Brun, *Chem. Zeit.*, 1893.

Effect of Steaming on Tensile Strength of Woolen Cloth[1]

Steaming at 100°C, hr	Relative strength		
	Warp	Filling	Mean
Original cloth	100	100	100
3	86	78	82
6	80	75	77
12	75	69	72
24	68	53	60
36	62	37	50
48	40	32	36
60	29	23	26

[1] Scheurer, *Bull. Soc. Ind. Mulh.*, 1893.

Effect of Moisture on Cotton Yarn in Finishing

Moisture in yarn, %	Breaking strain
2.89 (dry)	39.9
8.93 (usual)	64.0
17.36 (moist)	69.2

REGAIN

Regains in Conditioning Various Fibers Fixed by the International Congress at Turin

	%
Silk	11
Wool (tops)	18¼
Wool (yarn)	17
Cotton	8½
Linen	12
Hemp	12
Jute	13¾
New Zealand hemp	13¾

Percentage of Moisture in Textile Materials Corresponding to Percentage of Regain

Regain, %	Moisture, %	Regain, %	Moisture, %
5	4.76	12.5	11.11
6	5.66	13	11.50
7	6.54	14	12.28
7.5	6.98	15	13.04
8	7.41	16	13.79
8.5	7.83	17	14.53
9	8.26	18	15.25
10	9.09	19	15.97
11	9.91	20	16.67
12	10.71		

Table of Regain for Cotton at Various Temperatures and Percentages of Humidity

Humidity, %	°F					
	50	60	70	80	90	100
40	5.90	5.79	5.65	5.47	5.25	5.05
50	6.89	6.78	6.63	6.45	6.18	5.86
60	8.00	7.87	7.69	7.44	7.13	6.80
70	9.14	9.00	8.79	8.58	8.32	8.05
80	10.58	10.42	10.23	9.95	9.70	9.60
90	12.28	12.10	11.85	11.56	11.43	11.85
100	14.12	14.00	13.80	13.65	13.70	14.50

Regain in Worsted Tops at 70°F at Different Relative Humidities of the Air

Relative humidity, %	Regain, %
45	13.33
55	14.51
65	15.37
75	16.38
85	18.92

HEAT CONDUCTIVITY

Heat Conducting Powers of Textile Materials

	Relative values
Slag wool	100
Hair felt	117
Cotton felt	122
Sheep's wool	126
Air space	280

Comparative Values of Fibers as Non-Conductors of Heat[1]

A mass of the non-conducting material 1 in. thick was placed on a flat surface of iron kept heated to 310°F; the amount of heat transmitted per hr through the non-conductor was measured in lb. of water heated 10°F, the unit of area being 1 sq. ft. of covering:

Substance	Lb. water heated 10°F	Solid matter in 1 sq. ft., 1 in. thick, parts in 1000	Air occluded, parts in 1000
Loose wool	8.1	56	944
Goose feathers	9.6	50	950
Carded cotton	10.4	20	980
Hair felt	10.3	185	815
Fine asbestos	49.0	81	919
Air alone	48.0	0	1000

[1] Ordway, Eng. Min. J., **1890**, 650.

Heat Retaining Value of Clothing Materials

Count Rumford heated a large thermometer to 70°R and then ascertained the length of time required for the thermometer to fall to 10°R when surrounded with various textile materials, as follows:

	Sec
Air	576
Raw silk	1284
Sheep's wool	118
Cotton	1046
Fine lint (linen?)	1032
Beaver's fur	1296
Hare's fur	1315
Eiderdown	1305

In another series of experiments, however, using the same materials differently arranged, different results were obtained, as follows:

	Sec
Sheep's wool, loosely arranged	1118
Woolen thread, wound round bulb	934
Cotton, loose	1046
Cotton thread, wound round bulb	852
Lint, loose	1032
Linen thread, wound round bulb	873
Linen cloth, wound round bulb	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material.

FIREPROOFING

Minimum Quantity of Chemical Substances Required to Render 100 Parts of Cotton Non-inflammable (Duhem)

Reagent	Parts by weight
Tungstate of ammonium	12
Sulfate of ammonium	4½
Phosphate of sodium	30
Chloride of sodium (common salt)	35
Phosphate of calcium	30
Phosphate of magnesium	30
Chloride of magnesium	4–5
Phosphate of zinc	20
Sulfate of zinc	4½
Borate of aluminum	24
Aluminum hydrate	3
Chloride of ammonium	4½
Phosphate of ammonium	4½
Silicate of sodium	50
Borax	8½
Chloride of calcium	4½
Sulfate of magnesium	15
Chloride of potassium	45
Borate of zinc	20
Phosphate of aluminium	30
Boric acid	10
Silicic acid	30

LITERATURE

(For a key to the periodicals see end of volume)

For much additional material on textile fibers and a fairly complete bibliography, *see* Matthews, *The Textile Fibers.* 4th ed., New York, Wiley, 1924.

TANNINS AND VEGETABLE TANNING MATERIALS

John Arthur Wilson

and

Arthur W. Thomas

The tabulation of the properties of tanning substances of vegetable origin is complicated by the facts that the chemistry of these exceedingly complex substances is still in its infancy, the literature is not always clear, due to confusion in terminology, and the authenticity of the specimen studied is often uncertain. Formulas, especially those reported in the literature before 1910, are of little value, except as they indicate the relative percentages of C, H and O.

CLASSIFICATION

The earlier classification, based upon color reactions with ferric salts, is of no present value. Two systems are now used: Perkin (34) and Freudenberg (13).

Perkin's classification: α, Gallotannins (Depsides); β, Ellagitannins (Diphenylmethylolids); γ, Catecholtannins (Phlobatannins). These are characterized by the following reactions: *$FeCl_3$:* α, blue; γ, green. *Boiling dilute H_2SO_4:* α, gallic acid is formed; β, ellagic acid ppts.; γ, phlobaphenes or "reds" ppt. *Br:* γ give a ppt. *HCl and pine wood:* γ give phloroglucinol reaction, while α and β do not. *$C_6H_5N:NCl$:* γ give a ppt., indicating the presence of phloroglucinol or resorcinol groups, while α and β do not. *Fusion with alkali:* α yield gallic acid and a little pyrogallol; γ yield protocatechuic acid. *Heating in glycerol:* α form pyrogallol; γ form catechol. *HCHO and HCl*: γ give complete precipitation, the others do not. *Lead acetate in CH_3CO_2H:* α are pptd., γ are not.

Freudenberg's classification: **A.** Hydrolyzable tannins in which the benzene nucleus is united to a larger complex through the O atoms. **A1.** Mutual esters of phenolcarboxylic acids or with other hydroxy-acids (Depsides). **A2.** Esters of phenolcarboxylic acids with polyatomic alcohols and sugars. **A3.** Glucosides. In this group gallic acid predominates as the phenolic component. There is also the extraordinary distribution of combined caffeic acid and the presence of a new phenolcarboxylic acid in chebulinic acid. The ellagic acid glucosides also belong here. The most important criterion for the inclusion in this group is the splitting into simple components by hydrolyzing enzymes, especially tannase and emulsin.

B. Condensed tannins in which C linkages hold the nuclei together. These are not decomposed into simple components by enzymes. They are generally, not always, precipitated by bromine and under the influence of oxidizing agents or strong acids condense to high molecular weight tannins or "reds." By drastic treatment, preferably by alkalis, the C skeleton is broken up and phloroglucinol, if present, is dissolved out while the remainder of the molecule is transformed mainly into phenolcarboxylic acids. **B1.** Simple ketones such as hydroxybenzophenones and hydroxyphenylstyryl ketones. The phloroglucinol and benzene nuclei are present in equimolecular proportions. **B2.** This group is more complicated. The phloroglucinol and benzene nuclei are present in equimolecular proportions. This class embraces the catechols with their corresponding tannins and "reds." This is the most important class of technically used tannins. **B3.** There is practically nothing that can be said about this class of condensed tannins. It is even impossible to state whether they are really jointly condensed systems. In common with the first class of the condensed tannin group, they are precipitated by bromine and are transformed into "reds." On the other hand, they contain no phloroglucinol nucleus. It is possible that the hydroxycinnamic acids are characteristic components of this class; caffeic acid itself is readily transformed into condensation products of the nature of "reds."

In the following tables, the information is given in the following order: Name; classification (Perkin's being indicated by Greek letters, Freudenberg's by the above combinations of letters and figures); (1), source; (2) color and form in which it is isolated; (3) formula; (4) solvents; (5) specific rotatory power; (6) color with ferric salts; (7) remarks as to constitution, etc.

I. Natural Tannins

Beech tannin. γ. (1) Bark of red beech. (3) $C_{20}H_{22}O_9$ ([34]).

Caffetannic acid. γ. (1) Coffee berries as Ca and Mg salts; cainia root, *Chiococca brachiata; Nux vomica;* St. Ignatius beans; Paraguay tea, *Ilex paraguensis.* (2) Amorphous powder. (4) H_2O, C_2H_5OH. (6) Dark green ([34]).

Callutannic acid. γ. (1) Heather, *Calluna vulgaris.* (2) Amber colored powder. (6) Dark green ([34]).

Canaigre tannin. γ. **B3.** (1) Tuberous roots of the sorrel, *Rumex hymenosepalus.* (2) Bright yellow powder. (3) C, 58.10; H, 5.33 ([34]). (4) H_2O, C_2H_5OH. (6) Green ([13, 34]).

Catechol. γ. **B2.** (6) Green. *See* Table 3.

Chebulinic acid, Eutannin. α. **A2.** (1) Myrobalans, fruit of the *Terminalia chebula.* (2) Rhombic prisms, also colorless needles ([34]). (3) C, 50.60; H, 3.65. Probably $C_{34}H_{30}O_{22}$ ([16]). Air-dry substance contains 16.5% H_2O of crystn., which is lost at 100° ([2]). Mol. wt. by titration and by boiling point elevation in acetone, 806 ([16]). (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate ([13]). (5) α_D, +61.7° to 66.9° (H_2O) ([5]). α_D^{18}, +85° ±4° (abs. C_2H_5OH) ([11]); α_D^{22}, −60 (acetone, 1%) ([2]). α_D +59° to 67° (C_2H_5OH, 1–2%)([13]). (6) Blue-black. (7) Apparently union between di-gallolyl-glucose and the dibasic acid, $C_{14}H_{14}O_{11}$ with elimination of $2H_2O$ ([11, 16]). D. at 234° ([34]).

Cherry bark tannin. γ. (1) Bark of *Prunus cerasus.* (3) $C_{21}H_{20}O_{10}.0.5H_2O$. (6) Green ([34]).

Chestnut tannin. α. **A3.** (1) Leaves, bark and wood of Spanish chestnut, *Castanea vesca.* (3) Purified tannin, C, 50.79; H, 3.32. Mol. wt. 400 or multiple as detd. by titration ([24]). (4) H_2O. (6) Dark green to blue. (7) Tannin from leaves, wood and bark identical. Raw tannin is mixture containing quercetin, sugar, ellagic and gallic acids. Contains no phloroglucinol. Probably similar to tannin of German native oak ([24]).

Chinese tannin. *See* Gallotannin.

Chlorogenic acid. **A1.** (1) Monopotassium salt combined with one molecule of caffein in coffee beans. (2) Cryst. (3) $C_{16}H_{18}O_9.0.5H_2O$. (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate. (5) α_D, −33.1° (H_2O, 1–3%). (6) Green ppt. (7) 3, 4-Dihydroxy-cinnamoyl-quinic acid ([13]).

Cinchona tannin, quinotannic acid. γ. **B3.** (1) Cinchona bark. (2) Light yellow powder. (3) $C_{14}H_{16}O_9$(?) ([34]). (4) H_2O, C_2H_5OH ([13]). (6) Green ppt. (7) Very hygroscopic.

Cocatannic acid. γ. (1) Leaves of *Erythroxylon coca.* (2) Yellow micro. cryst. (3) $C_{17}H_{22}O_{10}.2H_2O$(?) (6) Green ([34]).

Colatein. γ. **B2.** (1) Cola nuts, *Cola acuminata.* (4) Hot H_2O, C_2H_5OH, acetone. (6) Green. (7) M. P. 257°–288° ([13]).

Colatin, Colatannin. γ. **B2.** (1) Cola nuts, *Cola acuminata.* (2) Cryst. ([13]). Light red amorphous powder ([34]). (3) $C_{16}H_{20}O_8$ ([34]). (4) C_2H_5OH, acetone, ethyl acetate. (5) Inactive. (6) Green. (7) M. P. 148° ([13]).

Cortepinitannic acid. γ. (1) Bark of Scotch fir, *Pinus sylvestris.* (2) Bright red powder. (3) $C_{32}H_{34}O_{17}$. (6) Intense green ([34]).

Cyanomaclurin. **B2.** (1) Wood of *Artocarpus integrifolia.* (2) Cryst. (3) $C_{15}H_{12}O_6$. (6) Violet. (7) M. P. above 290° ([13]).

***m*-Digallic acid.** α. **A1.** (1) Esterified with glucose in Chinese tannin; also synthetic. *See* Table 2.

Ellagic acid. β. (1) From many tannins containing ellagitannin by boiling with dilute H_2SO_4. Divi-divi, myrobalans and valonia best sources; also synthetic. *See* Table 2.

Filitannin. γ. **B2.** (1) Fern-root, *Aspidium filix-mas.* (2) Red-brown powder ([34]). (3) $C_{41}H_{26}NO_{18}$(?) ([29, 34]). (4) C_2H_5OH, H_2O ([29]). (5) Inactive ([13]). (6) Olive-green. (7) Heated at 125°, loses water and becomes insoluble ([13]).

Fraxitannic acid. γ. (1) Leaves of ash tree, *Fraxinus excelsior.* (2) Brownish-yellow deliquescent powder. (3) $C_{26}H_{32}O_{14}$ (?) ([29, 34]). (4) H_2O, C_2H_5OH ([29, 34]). (6) Dark green ppt. (7) Heated at 100°, loses water and becomes practically insoluble. Yields quinone upon oxidation by permanganate ([29, 34]).

Galitannic acid. γ. (1) Bark of *Galium verum.* (3) $C_{14}H_{16}O_{10}.H_2O$. (6) Green ([34]).

Gallotannin, Gallotannic acid, Tannin, Tannic acid. α. **A2.** (1) From galls on leaves and buds of various species of oak, especially *Quercus infectoria* and *Q. lusitania* ("Turkish tannin") due to puncture by insects of the genus *Cynips.* From galls on leaves and buds of a species of sumach, *Rhus semialata* ("Chinese tannin") due to puncture of insect, *Aphis chinensis.* (2) Light yellow-brown powder. (3) Average of several specimens, C, 52.59 to 53.70; H, 3.24 to 3.40 ([6]). $C_{76}H_{52}O_{46}$ (E. Fischer). Mol. wt., 1247–1636 by boiling point elevation in acetone. (4) H_2O, C_2H_5OH, ethyl acetate. (5) α_D^{20}, +58° to +70° (different specimens, H_2O); α_D^{20}, +18° (one specimen, C_2H_5OH) ([1, 6]); α_D^{22}, +12.9° (acetone); α_D^{22}, +17.6° (purified specimen, C_2H_5OH) ([1, 3]). (6) Bluish-black. (7) Hydrolysis of purified specimen by dil. H_2SO_4 yields 93.6% gallic acid and 6.8% glucose ([1, 3]). Undoubtedly a mixture of at least two individuals ([34]). The tannin, according to E. Fischer, is penta-*m*-digalloylglucose. Nierenstein objects, asserting that gallotannin is probably a glucoside of polydigalloyl-leucodigallic acid anhydride or of its free acid ([31]).

Gallotannin, Chinese Tannin. α. **A2.** (1) *See* Gallotannin above. (2) Amorphous yellow to light brown powder. (3) Penta-*m*-digallolyglucose. Mol wt., 1700 ([13]). (4) *See* Gallotannin above. (5) α_D^{26}, +73° (purified specimen, H_2O, 1%) ([1, 7]); α_D, +45° to +53° (H_2O, 20%), rising rapidly on dilution to +135° to +140° (H_2O, 1.2%) ([13]); α_D in formamide, +13°; acetone, +14°; C_2H_5OH, +18°, glacial acetic acid, +25°; pyridine, +40°. These all showed high and low α_D fractions in water; were alike in organic solvents. Colloidal forms and impurities markedly affect α_D in water ([23]). Two fractions—(a) α_D, +30° to +40° (H_2O); +40° to +41° (pyridine); (b) α_D, +150° to +158° (H_2O); +50° to +51° (pyridine) ([27]). Purified tannin, after removing part difficultly soluble in water, α_D, +13.9° (C_2H_5OH, 3%); +14.9° (C_2H_5OH, 10%); +13.1° (acetone, 10%) ([1, 4]). Potassium salt, containing 10.2% K, α_D^{18}, +46.3° (H_2O, 1%) ([1, 4]). (6) Bluish-black. (7) Upon hydrolysis with dil. H_2SO_4 there is produced 88.6% gallic acid and 11.4% glucose ([13]). This tannin is a mixture of deka-, nona-, and octa-gallolyl-glucoses averaging 8 to 9 gallic acid radicals to 1 molecule glucose. The fractions of lower α_D contain more depside-like gallic acid ([27]). *See also* gallotannin above.

Gallotannin, Turkish Tannin. α. **A2.** (1) *See* Gallotannin above. Aleppo galls. (2) Amorphous yellow to light brown powder. (3) C, 52.5; H, 3.5 ([13]). (4) *See* Gallotannin above. (5) α_D^{17}, 2.5° (H_2O, 7%); α_D, +5° (H_2O, 7% and less); α_D^{14} +23.2° to +24.2° (acetone, 10%) ([1, 8]). (6) Bluish-black. (7) Hydrolysis of purified specimens with dil. H_2SO_4: 81.8 to 84.8% gallic acid; 2.7 to 3.8% ellagic acid; 11.5 to 13.8% glucose; 2.0 to 4.1% tannin residue ([1, 8]). Hydrolysis and fractionation give a series of fractions of increasing α_D in alcohol from 15.7° to 43.7°. Concomitantly there is a decrease in ellagic and increase in gallic acid content. The ellagic acid is a part of the tannin molecule. At least 25% of the gallic acid is in depside form, partly directly bound in ester form to the sugar hydroxyl groups ([28]).

Gallnut Tannin. α. **A2.** (1) Galls on acorn cups of *Quercus robur* and *Q. pedunculata.* (3) C, 52.0; H, 3.3 ([13]). (7) Undoubtedly identical with gallotannin.

Hamamelitannin. α. **A2.** (1) Bark of *Hamamelis virginica.* (2) Fine white needles ([13]). (3) C, 49.9; H, 4.0; H_2O of crystn. 17.9%, approximating $C_{20}H_{20}O_{14}.6H_2O$ ([10, 18]). (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate ([13]). (5) α_D^{22}, +29° (H_2O,

2.35%); α_D^{23}, +33° (H_2O, 1.24%); α_D^{20}, +35.6° (another specimen, H_2O, 1.2%) [10]. (7) Contains no free carboxyl group. Acidity, equal to that of pyrogallol, is due to phenolic hydroxyls [10, 18]. Upon hydrolysis with dil. H_2SO_4: gallic acid, 70%; sugar, 30%. Upon hydrolysis with tannase: gallic acid, 66%; sugar, 34% [13]. M. P., 115°–117° (air-dry); 203° (dried at 100°) [34].

Hemlock tannin. γ. (1) Hemlock bark, *Tsuga (Abies) canadensis.* (3) $C_{20}H_{18}O_{10}$ (?). (7) Probably related to quercitannic acid of the oak [29, 34].

Horsechestnut tannin. γ. (1) Nearly all parts of the *Aesculus hippocastanum* and in root bark of apple tree. (2) Nearly colorless powder. (3) $C_{26}H_{24}O_{12}$. (6) Green [34].

Ipecacuanhic acid. γ. (1) Roots of *Psychotria ipecacuanha.* (2) Reddish-brown hygroscopic substance. (3) $C_{14}H_{18}O_7$. (6) Green [34].

Larch tannin. γ. (1) Bark of the larch, *Larix europea.* (6) Green [34].

Maclurin. **B1.** (1) Wood of "old fustic," *Chlorophora tinctoria;* also synthetic. (2) Yellow crystals [13]. Colorless needles when pure [34]. (3) $C_{13}H_{10}O_6$. (4) 14°, 1 part in 190 parts H_2O [13]. (6) Green. (7) 2, 4, 6, 3′, 4′-Pentahydroxybenzophenone, M. P. 200° (anhydrous form) [34].

Maletto tannin. γ. **B2.** Bark of *Eucalyptus occidentalis* and other species of *Eucalyptus.* (2) Brown powder. (3) $(C_{19}H_{20}O_9)_n$ [29, 34]. (4) H_2O, abs. C_2H_5OH (from which it is precipitated by ether) [13]. (7) Similar to quebracho tannin [13, 34].

Mangrove tannin. γ. **B2.** (1) *Rhizophora mangle, R. mucronata, Ceriops candolleana, C. roxburghiana.* (2) Amorphous red powder. (3) $C_{24}H_{26}O_{11}$ [29]. (6) Green. (7) Closely resembles catechutannic acid [34].

Mimosa tannin. γ. (1) Various species of *Mimoseae* such as *Acacia arabica* of Egypt and the "wattles" of Australia. (6) Bluish-violet. (7) With the exception of the reaction with ferric salts, gives all the ordinary reactions of the phlobatannins [34].

Oak tannin. **B3** [36]. (1) Leaves and buds of German oak, *Quercus pedunculata.* (2) Amorphous reddish-yellow powder [22]. (3) C, 49.9; H, 4.2. (4) H_2O, C_2H_5OH, acetone [22, 36]. (4) $\alpha_{\text{Hg yellow}}$, −39° ± 10° ($H_2O$); −30° ± 4° ($CH_3OH$) [21]. (7) Tannin from leaves of *Quercus sessiflora* identical [21]. Molecule contains 18–25% bound ellagic acid; 3–7% bound glucose; and the rest is an amorphous acid, "Quercus acid," C, 50.2; H, 3.6. Titration equivalent about 400 [21, 22].

Oak tannin, Quercitannic acid. γ. **B2.** (1) Bark of various species of *Quercus* [34]; Bark of *Quercus robur* [13]. (2) Reddish-white powder [34]. Light brown powder [13]. (3) $C_{20}H_{20}O_4$ (?): C, 59.79; H, 5.0 [34]. C, 56.8; H, 4.4. C, 55.4; H, 4.1 [13]. (6) Green [34]. Black-blue [13].

Oak tannin, Quercin, Quercic acid, Quercinic acid. γ. **B2.** (1) Wood of various species of *Quercus.* (2) Light brownish-yellow [34]. (3) $C_{16}H_{12}O_9.2H_2O$ [29, 34]. C, 48.3; H, 4.5 [13]. (6) Blue.

Paullinio tannin, Guarana tannin. γ. **B2.** (1) "Guarana paste" from seeds of *Paullinia cupana.* (2) Small colorless crystals [34]. Gray needles [30]. (3) $C_{17}H_{15}O_{18}.COOH.2H_2O$ [30]. (4) H_2O, C_2H_5OH, ethyl acetate, glacial acetic acid [30]. (5) α_D^{20}, −74.4° (H_2O, 10%); α_D^{18}, −39.1° (C_2H_5OH, 8%); −48.1° (acetone, 6%); α_D^{20}, −56.8° (initial rotation in pyridine, 8%. By mutarotation falls to constant value of −8.6°) [30]. (7) M. P. 199°–201° with evolution of CO_2. Loses two mol. H_2O of crystn. at 130°. M. P. of anhydrous form 259°–261° with evolution of CO_2 [30]. Paullinia catechol isolated from paullinia tannin is identical with "acacatechin" in crystal form and chemical properties. Chemically it is identical with gambier-catechin [13].

Pinicortannic acid. γ. (1) Bark of Scotch fir, *Pinus sylvestris.* (2) Reddish-brown powder. (3) $(C_{16}H_{18}O_{11})_2.H_2O$. (6) Green [34].

Pistachio tannin. γ. **B2.** (1) Leaves of mastic tree, *Pistachia lentiscus.* (2) Pale brown brittle mass [34]. (4) H_2O, C_2H_5OH, ethyl acetate [13]. (6) Blue-black. (7) Often sold for sumach [34].

Pomegranate tannin, Ellagitannin. β. **A3.** (1) Root bark of *Punica granatum.* (2) Amorphous greenish-yellow powder. (3) $C_{20}H_{16}O_{13}$ [34]. Two fractions: A (sol. in H_2O), C, 50.9; H, 3.4. B (insol. in H_2O), C, 52.4; H, 3.4 [13]. (4) Fraction A: H_2O, C_2H_5OH, ethyl acetate [13]. (6) Blue-black. (7) Glucoside of ellagic acid and hexose [13].

Quebracho tannin. γ. **B2.** (1) Wood of *Quebracho colorado, Schinopsis lorentzii* and *Balsanae.* (2) Red powder. (3) C, 62.5; H, 5.4. (4) Hot H_2O, C_2H_5OH, ethyl acetate, acetone [13]. (6) Green. (7) Tannin is mixture of products insol. in H_2O and sparingly sol. in cold H_2O. A benzoyl derivative, C, 73.0; H, 4.2, showed a mol. wt. in benzene of about 2300.

Rhatany tannin. γ. Bark of root of rhatany, *Krameria triandra.* (2) Light yellow powder. (4) H_2O. (6) Green [34].

Rheotannic acid, Rhubarb tannin. γ. **B2.** (1) Rhubarb. (2) Yellowish-brown powder. (3) $C_{26}H_{26}O_{14}$ [34]. (4) H_2O. (6) Black-green ppt. (7) Contains two glucosides, glucogallin ($C_{13}H_{16}O_{10}$) and tetrarin ($C_{32}H_{32}O_{10}$) [34]. Catechin also present which is probably identical with gambier-catechin [13].

Rubitannic acid. γ. (1) Leaves of *Rubia tinctorum.* (3) $C_{14}H_{22}O_{12}.0.5H_2O$. (6) Green [34].

Sequiatannic acid. γ. (1) Cones of *Sequoia gigantea.* (2) Reddish-brown powder. (3) $C_{21}H_{20}O_{10}$ [29, 34]. (4) H_2O, C_2H_5OH. (6) Brown-black ppt.

Spruce bark tannin. γ. (1) Bark of spruce. (3) $C_{21}H_{20}O_{10}$ (?) [34].

Sumach tannin. α. **A2.** (1) From leaves of many species of *Rhus.* Also *Coriaria myrtifolia* (French), *Colpoon compressum* (Cape), *Arctostaphylos* (Russian). (2) Yellow powder. (3) C, 52.3; H, 3.5. (*Rhus coriaria*) [13]. (4) H_2O, C_2H_5OH, ethyl acetate. (7) Similar to Turkish tannin.

Tannecortepinic acid. γ. (1) Bark of young Scotch firs in spring time. (3) $C_{28}H_{26}O_{12}$. (6) Green [34].

Tannic acid. *See* Gallotannin.

Tea tannin. γ. **A2.** (1) Leaves of black tea. (4) H_2O, ethyl acetate. (5) α_D, −177.3° [29]. (7) Probably identical with quercitannic acid [29, 34]. A gallotannin [13].

Tormentilla tannin. γ. (1) Root of *Potentilla tormentilla.* (2) Amorphous reddish powder. (3) $C_{26}H_{22}O_{11}$. (6) Blue-green [34].

Turkish tannin. *See* Gallotannin.

Willow bark tannin. γ. (1) Bark of *Salix triandra.* (6) Green. (7) Glucoside tannin [34].

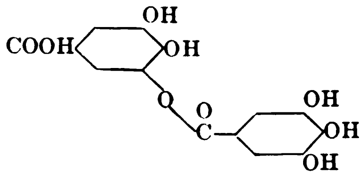
II. Synthesized Tannins

***m*-Digallic acid.** α. A1. (2) Fine needles. (3) I [13]. (4) CH_3OH, C_2H_5OH, $C_5H_{11}OH$. 23°, 1 part in 950 parts H_2O; 1 part in 350 parts ethyl acetate; 1 part in 2000 parts ether [1, 5]. 25°, 1 part in 1900 parts H_2O. 100°, 1 part in 50–60 parts H_2O [13]. (5) Inactive. (6) Blue-black. (7) Found esterified with glucose in Chinese tannin. When hot aq. solution is chilled, it jellifies [13]. M. P., 275° (282° corr.) with foaming and decomposition [1, 5].

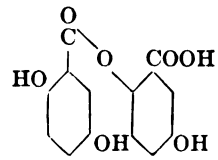
Digalloyl-levoglucosan. **A2.** (2) Micro-needles. (3) $C_{20}H_{18}O_{13}$. (4) H_2O, C_2H_5OH, acetone. (5) α_D^{18}, −27.9° (C_2H_5OH, 1.8%). (6) $FeCl_3$ gives blue-black ppt. in C_2H_5OH solution. (7) Decomposes 220°, carbonizes 270° [26].

Digentisic acid. α. (2) Fine needles. (3) II. (4) 0°, 1 part in 900 parts H_2O. (5) Inactive. (6) Fugitive blue and ppt. [1, 5]. (7) Dry form melts 204°–205° (208°–209° corr.) with sintering.

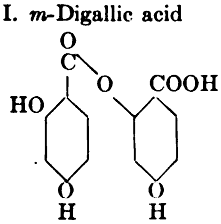
Diprotocatechuic acid. α. (2) Fine needles. (3) $(OH)_2C_6H_3$-$CO.O.C_6H_3(OH)COOH$. (4) Acetone, CH_3OH. 1 part in 2500 parts H_2O. (5) Inactive. (6) Blue-green. (7) M. P., 237°–239° (corr.) (1, 5).



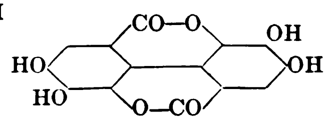
I. *m*-Digallic acid



II. Digentisic acid



III. Di-β-resorcylic acid



IV. Ellagic acid

Di-β-resorcylic acid. α. (2) Micro-needles. (3) III. Isomeric with digentisic acid. (4) C_2H_5OH, acetone, ethyl acetate, hot H_2O, ether. (5) Inactive. (6) Violet red. (7) Foams and decomposes at about 210° (215° corr.) (1, 5).

Ellagic acid. β. (2) Cryst. from pyridine in prismatic needles which are converted by C_2H_5OH to a pale yellow cryst. powder. (3) $C_{14}H_6O_8.2H_2O$. IV. (5) Inactive. (7) Above 360° sublimes with carbonization (34). Not a true tannin. *See* Table 1.

Hexagalloyl mannite. **A2.** (2) Amorphous brown powder. (3) $C_6H_8O_6[CO.C_6H_2(OH)_3]_6$. (4) H_2O, C_2H_5OH, acetone, ethyl acetate. (5) α_D^{18}, +27.0° (C_2H_5OH, 2%). (6) Dark blue (1, 4).

Maclurin. **B1.** *See* Table 1.

Penta-*m*-digalloyl-α-glucose. **A2.** (2) Light brown amorphous mass. (3) $C_{76}H_{52}O_{46}$. (4) 18°, 1 part in 200 parts H_2O. (5) Prepared by alkaline hydrolysis of acetates: α_D^{18}, +36°(C_2H_5-OH, 10%); +40° to 41° (acetone, 10%); 43.8° (H_2O, 1%) (1, 3). Prepared from acetates by CH_3OH and HCl: α_D^{18}, +41.3° (C_2H_5OH, 5%); +44.6° (acetone, 5%); +51° (H_2O, 0.5%) (1, 4). (6) Blue-black. (7) Potassium salt containing 10.3% K, α_D^{18} +56.6° (H_2O, 5%) (1, 4).

Penta-*m*-digalloyl-β-glucose. **A2.** (2) Light brown amorphous mass. (3) $C_{76}H_{52}O_{46}$. (4) 20°, 1 part in 1000 parts H_2O. (5) Prepared by alkaline hydrolysis of acetates: α_D^{18}, +14.9° (C_2H_5OH, 10%); +13.1° (acetone, 10%); +42.3° (H_2O, 1%) (1, 3). Prepared from acetates by CH_3OH and HCl: α_D^{18}, +10.8° (C_2H_5OH, 5%); +10.8° (acetone, 5%); +21° (H_2O, 0.1%) (1, 4). (6) Blue-black. (7) Apparently identical with Chinese tannin. Potassium salt containing 10.3% K, α_D^{18}, +33.7° (H_2O, 0.5%) (1, 4).

Pentagalloyl-α-glucose. **A2.** (2) Yellow mass. (3) $[(OH)_3$-$C_6H_2CO]_5C_6H_7O_6$. (4) H_2O, C_2H_5OH, ether (1, 3). (5) α_D^{18}, +66.5° (H_2O, 1%). α_D^{23}, 65.4° (H_2O, 1%). α_D^{20}, +77.0° (C_2H_5OH, 3%). α_D^{18}, 76.4° (C_2H_5OH, 2%) (1, 3). α_D^{16}, +60° (H_2O, 1%); +81.5° (C_2H_5OH, 2%) (1, 4). (6) Blue-black.

Pentagalloyl-β-glucose. **A2.** (2) Yellow mass. (3) $[(OH)_3C_6$-$H_2CO]_5C_6H_7O_6$. (4) H_2O, C_2H_5OH (1, 3). (5) α_D^{18}, +13.1° (H_2O, 1%); +13.6° (H_2O, 10%); +23.3° (C_2H_5OH, 2%) (1, 3). α_D^{18}, +15° (H_2O, 1%); +24° (C_2H_5OH, 2%). (6) Blue-black. (7) Potassium salt contains 10.1% K.

Pentapyrogallol-carboyl-glucose. **A2.** (2) Amorphous powder. (3) $[(OH)_3C_6H_2CO]_5C_6H_7O_6$. (4) Hot H_2O, C_2H_5OH, acetone. (5) α_D^{18}, +69° (H_2O, 2.5%). (6) Dark blue (1, 9). (7) Sinters at 160° and melts at about 200° with decomposition.

Tetragalloyl-erythrite. **A2.** (2) Cryst. (3) $[(OH)_3C_6H_2CO]_4$-$C_4H_6O_4$. (4) Hot H_2O, C_2H_5OH, acetone, mixtures of H_2O and C_2H_5OH. (7) Decomposes at about 308° (1, 4).

Tetragalloyl-α-methylglucoside. **A2.** (3) $C_{35}H_{30}O_{22}$. (4) Identical with pentagalloyl-glucoses. (5) α_D^{20}, +26.4° (H_2O, 4%). (6) Identical with pentagalloyl-glucoses in reactions. (7) M. P. 130°–140° with decomposition (1, 6).

Trigalloyl-acetone-glucose. **A2.** (2) Amorphous light brown mass. (3) $[C_6H_2(OH)_3CO]_3C_6H_7O_6(C_3H_6)$. (4) Warm H_2O, CH_3OH, C_2H_5OH, acetone, ethyl acetate. (5) α_D^{20}, −93° (dry acetone, 4%). (6) Blue-violet (1, 2).

Trigalloyl-glucose. **A2.** (2) Amorphous yellowish brown mass. (3) $[C_6H_2(OH)_3CO]_3C_6H_9O_6$. (4) Cold H_2O, CH_3OH, C_2H_5OH, acetone, ethyl acetate, pyridine. (5) α_D^{20}, −118° (dry acetone, 2.5%). (6) Deep violet (1, 2).

Trigalloyl-glycerol. **A2.** (2) Amorphous yellowish brown mass. (3) $[(OH)_3C_6H_2CO]_3C_3H_5O_3$. (4) H_2O, acetone, ethyl acetate, warm ether. (6) Deep blue (1, 4).

α-Trigalloyl-levoglucosan. A2. (2) Micro. hexagonal crystals. (3) $C_{27}H_{22}O_{17}$. (4) Hot acetone. (5) α_D^{18}, −18.0° (C_2H_5OH, 19%). (6) $FeCl_3$ gives blue-black ppt. in C_2H_5OH solution. (7) Decomposes 250°–300°, carbonizes 320° (26).

β-Trigalloyl-levoglucosan. **A2.** (2) Micro-needles. (3) $C_{27}H_{22}$-O_{17}. (5) α_D^{18}, −21.0° (C_2H_5OH, 1%). (6) $FeCl_3$ gives blue-violet ppt. in C_2H_5OH solution. (7) Decomposes 270°, carbonizes 320° (26).

III. Catechols or Catechins

***d*-Catechol.** (1) Acacia and gambier catechus. (2) Thin needles. (3) $C_{15}H_{14}O_6.4H_2O$ (20). (4) C_2H_5OH, ethyl acetate, pure ether. Anhydrous form almost insoluble in latter two. (5) α_{578}, +17° (50% acetone, 9%) (14, 15, 19, 20). α_{578}, ±0° (C_2H_5OH) (20). α_D, −2° (C_2H_5OH) (20). α_D^{18}, −0.47° ±0.03° (C_2H_5OH, 9%); +3.7° ± 0.5° (50% C_2H_5OH, 9%). α_D^{20}, +18.4° ± 0.9° (H_2O, 0.9%, increasing markedly with temperature decrease) (14). (7) For discussion of structural formula *see* (20, 29, 33). M. P. 93°–95°; anhyd., 174–5°.

***l*-Catechol.** (1) Isolated from acacia and gambier catechus. (2) Thin needles. (3) $C_{15}H_{14}O_6.4H_2O$. (5) α_{578}, ±0° (C_2H_5OH); α_{578}, −16.8° (50% acetone, 3%) (20). (7) M. P. 93°–95°; anhyd., 174°–175° (19, 20).

***dl*-Catechol.** (1) Principal constituent of catechol separated from acacia catechu. (2) Thin needles. (3) $C_{15}H_{14}O_6.3H_2O$. (7) Is "acacatechin" (19). Sinters at 100°, melts 214°–216° with decomposition (19, 20).

Catechol-a. (1) Acacia catechu (33, 35). (3) $C_{15}H_{14}O_6.3H_2O$ (35). (7) Is *dl*-catechol (14). Methylated "acacatechin" has same melting point and crystal form as synthetic methyl compound (14). M. P. 204°–205° (35).

Catechol-b, Gambier catechol. (1) Gambier catechu (33, 35). (7) Identical with *d*-catechol in crystal form, melting point, solubility, and constitution.

Catechol-c. (1) Gambier catechu. (2) Small pale yellow prisms (35). (3) $C_{15}H_{14}O_6$. (7) Identified as *d*-epicatechol (20). M. P. 235°–237° (35).

Chinese rhubarb catechol. (5) α_{578}, +18° (50% acetone) (15).

Mahogany catechol. (5) α_D, +23° (50% acetone). α_{578}, +16° (50% acetone); +15° (C_2H_5OH) (15).

Paullinia catechol. (5) Inactive in C_2H_5OH. α_D, +3.7° (50% acetone) (15).

***d*-Epicatechol.** (2) Thick prisms. (3) $C_{15}H_{14}O_6.4H_2O$. (5) α_{578}, +68.9° (C_2H_5OH, 7%); +59.9° (50% acetone, 4%). (7) M. P. 245° (20).

***l*-Epicatechol.** (1) Gambier and acacia catechus (19). (2) Thick prisms. (3) $C_{15}H_{14}O_6.4H_2O$ (19, 20). (5) α_{578}, −68.2° (C_2H_5-OH, 6%): −59.0° (50% acetone, 4%) (19, 20). (7) M. P. 245°.

dl-**Epicatechol.** (1) Gambier and acacia catechus ([19]). (2) Exists both as prisms and needles. (3) $C_{15}H_{14}O_6.4H_2O$. (7) M. P. of prisms, 224°–226° ([20]).

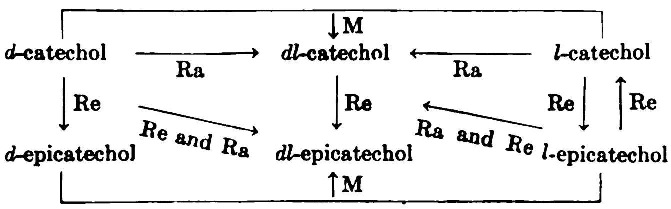
d-**β-Gambier catechol-carboxylic acid.** (2) Micro-needles. (3) $C_{16}H_{14}O_8$. (5) α_D^{20}, +12.6° (H_2O, 5%); +17.6° (C_2H_5OH, 7%). (7) M. P. 249°–251° with evolution of CO_2 ([30]).

l-**β-Gambier catechol-carboxylic acid.** (2) Large needles. (3) $C_{16}H_{14}O_8$. (5) α_D^{18}, −22.4° (H_2O, 5%). α_D^{17}, −31.6° (C_2H_5-OH, 6%). (7) M. P. 258°–261° with evolution of CO_2 ([30]).

dl-**β-Gambier catechol-carboxylic acid.** (3) $C_{16}H_{14}O_8$. (7) M. P. 252°–253° with evolution of CO_2 ([30]).

The relationship between the catechols and epicatechols is shown as follows:

M = mixing; Ra = racemizing; Re = rearrangement ([20]).



LITERATURE

(For a key to the periodicals see end of volume)

(1) Fischer, *Untersuchungen über Depside und Gerbstoffe*, 1919. (2) Fischer and Bergmann, *25*, **51**: 298; 18. (3) *Idem.*, *25*, **51**: 1760; 18. (4) *Idem.*, *25*, **52**: 829; 19. (5) Fischer and Freudenberg, *8*, **384**: 225; 11. (6) *Idem.*, *25*, **45**: 915; 12. (7) *Idem.*, *25*, **45**: 2709; 12. (8) *Idem.*, *25*, **47**: 2485; 14. (9) Fischer and Rapaport, *25*, **46**: 2389; 13.

(10) Freudenberg, *25*, **52B**: 177; 19. (11) *Idem.*, *25*, **52B**: 1238; 19. (12) *Idem.*, *25*, **53B**: 1416; 20. (13) *Idem.*, *Die Chemie der natürlichen Gerbstoffe*, 1920. (14) Freudenberg, Böhme and Beckendorf, *25*, **54B**: 1204; 21. (15) Freudenberg, Böhme and Purrmann, *25*, **55B**: 1734; 22. (16) Freudenberg and Fick, *25*, **53B**: 1728; 20. (17) Freudenberg, Orthner and Fekentscher, *8*, **436**: 286; 24. (18) Freudenberg and Peters, *25*, **53B**: 953; 20. (19) Freudenberg and Purrmann, *25*, **56B**: 1185; 23.

(20) Freudenberg and Purrmann, *8*, **437**: 274; 24. (21) Freudenberg and Vollbrecht, *8*, **429**: 284; 22. (22) *Idem.*, *25*, **55B**: 2420; 22. (23) Freudenberg and Scilasi, *25*, **55B**: 2813; 22. (24) Freudenberg and Walpuski, *25*, **54B**: 1695; 21. (25) Iljin, *52*, **83**: 422; 10. (26) Karrer and Salomon, *37*, **5**: 108; 22. (27) Karrer, Salomon and Peyer, *37*, **6**: 3; 23. (28) Karrer, Widmer and Staub, *8*, **433**: 288; 23. (29) Nierenstein, *Abderhalden's Biochemisches Handlexikon*, vol. 7, 1912.

(30) Nierenstein, *4*, **121**: 23; 22. (31) *Idem.*, *54*, **41**: 29; 22. (32) *Idem.*, *1*, **46**: 2793; 24. (33) Perkin, *4*, **87**: 398; 05. (34) Perkin and Everest, *The Natural Organic Coloring Matters*, 1918. (35) Perkin and Yoshitake, *4*, **81**: 1160; 02. (36) Vollbrecht, *259*, **1921**: 1.

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS

The names and tannin contents listed were taken from the literature at large for what they may be worth; in some cases the information given may be considerably in error. The place grown may indicate either the place where the sample analyzed was grown or the place where the material grows in abundance. In the majority of cases, at least, the tannin contents are supposedly those of the air-dried material.

In using the tannin figures, it should be recognized that they are not true tannin contents, but merely figures obtained by methods open to very serious question. A number of slightly different methods were used, but all conformed roughly to the following general scheme. A solution of the tanning material of concentration confined to certain limits was treated with lightly chrome-tanned hide powder until no tannin was left in solution; *i.e.*, the solution no longer gave a precipitate with gelatin solution. The decrease in concentration of all matters in solution was then taken as the measure of the tannin content. Obviously all substances of a slightly acid nature would be removed to some extent by the hide powder and hence all figures must be high where these are present.

The probable magnitude of the error was shown by Wilson and Kern for a number of the commoner tanning extracts. By first freeing the tannin solution of tannin by shaking with hide powder and then freeing the hide powder from nontannin by washing, they were able to estimate the tannin by the increase in weight of the dried hide powder. The tannin contents so obtained differed in many cases by startling amounts from those obtained by the methods generally accepted as official.

The comparison is with the official method of the American Leather Chemists' Association, which is similar in principle to the methods employed in other countries.[1]

Tanning material	Per cent tannin found	
	A. L. C. A. method	Wilson-Kern method
Chestnut wood extract	25.80	11.90
Gambier extract	24.95	7.79
Hemlock bark	10.06	6.17
Hemlock bark extract	26.68	23.38
Oak bark extract	24.20	12.88
Osage orange extract	39.87	13.37
Quebracho extract	68.01	47.41
Spruce bark extract	22.14	11.71
Sumac extract	25.51	16.29
Sumac leaves	25.56	9.61
Wattle bark extract	33.55	24.16

Many of the tanning materials are leached on a large scale by extract manufacturers and the concentrated extracts are available on the market showing a tannin content by the A. L. C. A. and similar methods of from 20 to 35% for liquid extracts and from 45 to 70% for solid extracts.

It may be assumed that nearly every form of plant life contains some tannin. The following list is not complete but is intended to serve as a guide to those whose interests might be directed into these fields of work.

[1] For a detailed comparison of the methods and their interpretation, see J. A Wilson, *The Chemistry of Leather Manufacture*, p. 215–31 (The Chemical Catalog Co., New York, 1923).

Source and Tannin Content of Vegetable Tanning Materials

Botanical name	Common name	Place grown	Per cent tannin
Abies alba	White spruce	Northern America	Bark 7–13
Abies canadensis	Hemlock fir	Northern America	Bark 8–15
Abies dumosa	Hemlock spruce	Northern America	Bark 10
Abies excelsa	Norway spruce	Northern Europe	Bark 7–13
Abies grandis	Lowland fir	California	Bark 9
Abies pectinata	Silver fir	Europe	Bark 6–15
Acacia acuminata	Raspberry jam wood	Australia	Bark 7–15
Acacia angica	Angica	Brazil	Bark 20–25
Acacia anema	Mulga	New South Wales	Bark 5–9
Acacia arabica	Babul	India	Bark 12–20 Pods 20–42
Acacia binervata	Black wattle	Australia	Bark 30
Acacia catechu	Cutch	India	Wood ext. 60
Acacia cavenia	Espinillo	South America	Pods 18–21 Bark 6
Acacia cebil	Red cebil	Argentina	Bark 10–15 Leaves 6–7
Acacia cunninghamii		Queensland	Bark 9
Acacia curupi	Curupy	South America	Bark 18
Acacia dealbata	Wattle	Africa and Asia	Bark 17–23
Acacia decurrens	Wattle	Australia	Bark 18–51
Acacia granulosa		New Caledonia	Bark 12
Acacia homalophylla	Yarran	New South Wales	Bark 9
Acacia horrida	Doornbosch	Cape Good Hope	Bark 8–18
Acacia koa	Koa tree	Hawaii	Bark 18
Acacia leptocarpa		Queensland	Bark 10
Acacia longifolia		Cyprus	Bark 15
Acacia melanoxylon	Blackwood	New South Wales	Bark 11 Leaves 3
Acacia microbotrya	Manna wattle	Australia	Bark 18–27 Leaves and twigs 20
Acacia mollissima	Green wattle	Australia	Bark 12–47
Acacia neriifolia		Australia	Bark 14
Acacia oswaldi	Miljie	Australia	Bark 10
Acacia penninervis	Hickory	Europe	Bark 14–38
Acacia podalyriaefolia		Queensland	Bark 12
Acacia polystachya		Queensland	Bark 18
Acacia pycnantha	Golden wattle	Australia	Bark 40–50
Acacia salicina		Australia	Bark 6–8
Acacia sentis		New South Wales	Bark 6
Acacia seyal	Talh	Sudan	Bark 18
Acacia sp.	Gallol	Somaliland	Bark 24
Acacia spiralis	Guaic	New Caledonia	Bark 17
Acer campbellii	Himalayan maple	India	Bark 3
Acer campestre	Field maple	Europe	Bark 4
Alchornea triplinervia	Tapia gwazu-ih	Paraguay	Bark 12
Allophylus edulis	Koku	Paraguay	Bark 10
Alnus firma	Minibari	Japan	Fruits 25
Alnus glutinosa	Alder	Europe	Bark 16–20
Alnus incana	Grey alder	Europe	Bark 10
Alnus maritima	Hannoki	Japan	Fruits 25
Alnus oregona	Red alder	Pacific states	Bark 9
Anacardium occidentale	Kashew nut	India	Bark 9
Anogeissus acuminata	Yon	India	Bark 10
Anogeissus latifolia	Dhawa	India	Bark 16 Leaves 10–18 Shoots 20–30 Red tips 54
Anogeissus pendula		India	Bark 9
Apuleia praecox	Yhvihra-pere	Paraguay	Bark 11
Arctostaphylos uva-ursi	Bearberry	Russia	Leaves and twigs 14
Areca catechu	Betelnut palm	India	Fruits 10–15
Aspidiosperma polyneuron	Palo rosa	Paraguay	Bark 3

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Aspidiosperma quebracho-blanco	White quebracho	Argentina	Leaves 27–28 Bark 4 Wood 3
Banksia integrifolia	Coast honeysuckle	Queensland	Bark 11
Banksia serrata	Heath honeysuckle	Australia	Bark 11–23
Bauhinia vahlii	Muhurain bark	India	Bark 9
Betula alba	White birch	Northern Europe	Bark 2–18
Betula lenta	Black birch	Northern America	Bark 3–18
Boswellia serrata	Salai bark	India	Bark 13
Bruguiera gymnorrhiza	Mangrove	East Africa	Bark 22–52
Bruguiera parviflora	Hagalay	Philippines	Bark 7–13
Bruguiera rhumphii	Mangrove	New Caledonia	Bark 27–42 Root bark 6 Root wood 9
Bumelia obtusifolia	Pihkasurembiu	Paraguay	Bark 8
Byrsonima cydoniaefolia	Mureci	Bolivia	Bark 20
Byrsonima spicata	Tamwood	South America	Bark 44
Cabralea sp	Cancharana	Paraguay	Bark 5
Caesalpinia brevifolia	Algarobilla	Chile	Pods 43–67
Caesalpinia cacolaco	Cascalote	Mexico	Pods 40–55
Caesalpinia coriaria	Divi-divi	Central America	Pods 30–50
Caesalpinia digyna	Tari	India and Burma	Pod cases 40–60
Caesalpinia melanocarpa	Guyacan	Argentina	Pods 15–23 Wood 8
Caesalpinia tinctoria	Celavinia	Central America	Pods 30–32
Callitris calcarata	Australian fir	Australia	Bark 17–31
Callitris glauca	Australian fir	Australia	Bark 12–15
Camellia thea	Tea	Asia and Africa	Leaves 5–10
Carissa spinarum		India	Leaves 8–12
Cassia auriculata	Tarwar	India	Bark 16–22
Cassia fistula	Amaltas	South India	Bark 11–15 Pod husk 17
Castanea pubinervis	Japanese chestnut	Japan	Bark 6 Wood 7
Castanea cesva	Spanish chestnut	Southern Europe Southern U. S.	Bark 6–8 Wood 7–11
Castanopsis chrysophylla	Western chinquapin	Pacific states	Bark 8
Castanopsis sinensis	Gie-gay	Indo-China	Bark 12
Casuarina	Ironwood	New Caledonia	Bark 10
Casuarina equisetifolia	Casagha pine	Southern Asia	Bark 11–18
Casuarina glauca	Bull oak	New South Wales	Bark 12
Ceanothus velutina	Snow bush	Western U. S.	Leaves 17
Ceriops candolleana	Bahau	India and Africa	Bark 24–42
Ceriops roxburghiana	Goran	India	Bark 13
Ceriops tagal	Tangal	Philippines	Bark 24–37
Cleistanthus collinus	Kodarsi		Bark 33
Cocos romanzoffiana	Pindo	Paraguay	Bark 7
Copaifera lansdorfii	Kupaih	Paraguay	Bark 17
Coriaria myrtifolia	French sumac	France	Leaves 15
Coriaria nepalensis		India	Leaves 20
Coriaria ruscifolia	Tutu	New Zealand	Bark 16–17
Corylus avellana	Hazel	Europe	Bark 5
Coulteria tinctoria	Tara	Algeria and Peru	Pods 43–51
Crossostylis multiflora	Bush mangrove	New Caledonia	Wood 21 Bark 3
Cryptomeria japonica	Japanese cedar	Japan	Bark 6
Cupania sp	Cedrillo	Paraguay	Bark 16
Cupania uraguensis	Kambuata	Paraguay	Bark 18
Cupania vernalis	Yaguarataih	Paraguay	Bark 15
Dalbergia sp	Yhsapih-ih	Paraguay	Bark 6
Dioscorea atropurpurea	Cu-nao	Indo-China	Tubers 20
Elaeocarpus grandis	Blue fig bark	New South Wales	Bark 10
Elephantorrhiza burchellii	Elephant roots	Africa	Root 6–22
Enterolobium timbouva	Timbo	Paraguay	Bark 22

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Eremophila longifolia	Emu bush	New South Wales	Bark 5 Leaves 10
Eucalyptus accedens	Spotted gum	Australia	Bark 18
Eucalyptus alba	Mountain gum	Australia	Bark 30–32
Eucalyptus amygdalina	Ribbon gum	New South Wales	Gum 58–65
Eucalyptus corymbosa	Bloodwood	New South Wales	Gum 28 Leaves 18 Bark 6
Eucalyptus diversicolor	Karri	Australia	Bark 16–20
Eucalyptus erythronema	White mallet	Australia	Bark 30
Eucalyptus falcata	Silver mallet	Australia	Bark 5–32
Eucalyptus globulus	Eucalyptus	Australia	Sap 28
Eucalyptus gunnii	Red gum	New South Wales	Leaves 17 Bark 11
Eucalyptus longifolia	Woolly-butt	Australia	Bark 8
Eucalyptus maculata	Spotted gum	New South Wales	Gum 45 Bark 10 Leaves 5
Eucalyptus loxophleba	York gum	Australia	Bark 5–10
Eucalyptus obliqua	Stringy bark	New South Wales	Bark 17
Eucalyptus occidentalis	Black mallet	Australia	Bark 20–26
Eucalyptus occidentalis astringens	Red mallet	Australia	Bark 40–50
Eucalyptus odorata	White box	New South Wales	Leaves 7
Eucalyptus piperita	Messmate	New South Wales	Gum 32–62 Leaves 13
Eucalyptus platypus	Round leaf moort	Australia	Bark 25
Eucalyptus redunca	Wandoo	Australia	Bark 16–20
Eucalyptus redunca oxymitra	Blue leaf mallet	Australia	Bark 22–30
Eucalyptus robusta	Mahogany	Florida	Leaves 12–17
Eucalyptus rostrata	Blue gum	Australia	Bark 16
Eucalyptus salmonophloia	Salmon gum	Australia	Bark 8–13
Eucalyptus salubris	Gimlet	Australia	Bark 16–19
Eucalyptus siderophloia	Red iron bark	New South Wales	Gum 35–73 Bark 10 Leaves 6
Eucalyptus sieberiana	Cabbage gum	New South Wales	Bark 37
Eucalyptus spathulata	Swamp mallet	Australia	Bark 26
Eucalyptus stellulata	Black gum	New South Wales	Bark 13 Leaves 17
Eucalyptus stuartiana	Apple	New South Wales	Bark 5 Leaves 10
Eucalyptus torquata	Flowering gum	Australia	Bark 17
Eucalyptus viminalis	Manna gum	New South Wales	Bark 8 Leaves 4
Eugenia braziliensis	Yhva-poroitih	Paraguay	Bark 43 Leaves 17 Wood 12
Eugenia jambolana	Java plum	India	Bark 19
Eugenia jambos		Brazil	Bark 12
Eugenia maire		New Zealand	Bark 16–17
Eugenia michellii	Nangapirih gwazu	Paraguay	Bark 29
Eugenia pungens	Yhva viyu	Paraguay	Bark 11
Eugenia smithii		Australia	Bark 17
Eugenia sp	Yhvajhay puihta gwazu	Paraguay	Bark 16–29
Exocarpus cupressiformis	Native cherry	Australia	Bark 15–16
Fiscus sp	Kili bark	Sudan	Bark 19
Fusanus acuminatus	Quandony	Australia	Bark 19
Garicinia mangostana	Mangoustan	Cochin-China	Fruit shells 14
Grevillia striata	Beefwood	Australia	Bark 18
Guarea sp	Guare	Paraguay	Bark 10
Hakea glabella		Australia	Bark 18
Hakea leucoptera	Needle bark	New South Wales	Bark 11
Heritiera fomes	Sundri bark	India	Bark 7

Source and Tannin Content of Vegetable Tanning Materials.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Hopea odorata		India	Bark 14–15 Leaves 11 Wood 10
Hopea parviflora	Ironwood	India	Bark 17–22
Hydnora longicollis	Ganib	Africa	Roots 32
Inga affinis	Inga gwazu	Paraguay	Bark 26
Inga feuillei	Paypay	Peru	Pods 12–15
Juniperus recurva	Weeping blue	Japan	Bark 8
Krameria triandria	Rhatany	Peru	Root bark 20
Larix dahurica	Larch	Japan	Bark 9
Larix europaea	Larch	Europe	Bark 9–10
Larix occidentalis	Western larch	N. W. United States	Bark 11 Wood 7
Laurus lingue		Chile	Bark 17–19
Leuceadendron argenteum	Silver tree	Cape Good Hope	Bark 9–16
Leucospermum conocarpum	Knotted tree	Cape Good Hope	Bark 10–22
Ludwigia caparossa	Caparossa	Brazil	Bark 20–25
Lysiloma candida	Palo blanco	Lower California	Bark 26
Maclura pomifera	Osage orange	Texas	Wood 11
Malpighia faginea	Nance	Mexico	Bark 26
Malpighia punicifolia	Mangrutta	Nicaragua	Bark 20–30
Mimosa farinosa	Mimosa	Argentina	Bark 4
Mimosa pudica	Mimosa	India	Roots 10
Mimosa sp	Yukeri gwazu	Paraguay	Bark 11
Myrica asplenifolia	Sweet fern	Michigan	Leaves 4–5 Roots 4–6
Myrica nagi	Box myrtle	India	Bark 13–27
Nauclea gambir	Gambier	East Indies	Leaves and twigs 5–6
Ocotea bullata		South Africa	Bark 6
Ocotea sp	Yhva-iha	Paraguay	Bark 11
Osyris abyssinica		Transvaal	Leaves and twigs 13–25
Osyris arborea		Northern India	Leaves 20
Osyris compressa	Cape sumac	Cape Good Hope	Leaves 17–23
Oxalis gigantea		Chile	Bark 25
Paullinia sorbilis	Guara	Brazil	Fruit 43–55
Peltophorium dubium	Yhvihra puihta	Paraguay	Bark 31
Pentacme suavis		India	Leaves 12–24 Bark 7–13 Wood 4
Phyllanthus emblica	Amla	India	Stoned fruit 26–35 Leaves 23–28 Bark 15–24
Phyllocladus asplenifolia	Celery-topped pine	Tasmania	Bark 23
Phyllocladus rhomboidalis		Tasmania	Bark 21
Phyllocladus trichomanoides		New Zealand	Bark 28–30
Picea glehni	Red yezomatsu	Japan	Bark 19
Picea sitchensis	Sitka spruce	Pacific states	Bark 12–18
Pinus cembra	Pine	Alpine Europe	Bark 3–5
Pinus densiflora	Red pine	Japan	Bark 6
Pinus halepensis	Aleppo pine	Mediterranean coasts	Bark 10–15
Pinus Khasya	Pine	Burma	Bark 7–10
Pinus longifolia	Long-leaved pine	India	Bark 11–14
Pinus muricata	Swamp pine	California	Bark 13
Pinus radiata	Monterey pine	California	Bark 14
Pinus sylvestris	Scotch fir	Northern Europe	Bark 4–5
Pinus thunbergii	Black pine	Japan	Bark 6
Piptadenia cebil		Argentina	Bark 15
Piptadenia rigida	Kurupaih-ra puihta	Paraguay	Bark 28
Pistacia lentiscus	Pistacio	Mediterranean	Leaves 12–19
Pistacia orientalis	Pistacio	India	Galls 30–40
Pithecolobium dulce	Camanchile	Mexico	Bark 15–25
Polygonum amphibium		Missouri	Roots 22 Branches 17
Polygonum bistorta	Snakeweed	England	Roots 16–21

Source and Tannin Content of Vegetable Tanning Materials.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Populus tremula	Poplar	Europe	Bark 3
Prosopis oblonga	Abu-surug	Sudan	Bark 14
Protea grandiflora		Cape Good Hope	Bark 15–16
Protea mellifera	Sugarbush	Cape Good Hope	Bark 18–25
Pseudotsuga taxifolia	Douglas fir	Pacific states	Bark 7
Punica granatum	Pomegranate	India	Fruit rind 27–30 Kernel 32 Bark 18–22
Quebrachia lorentzii	Quebracho	South America	Wood 20–30 Bark 6–8
Quercus aegilops	Valonia	Mediterranean	Acorns 17–40
Quercus agrifolia	Live oak	California	Bark 19
Quercus alba	White oak	Northern America	Bark 7
Quercus californica	Black oak	California	Bark 10
Quercus cerris	Turkey oak	Southern Europe	Galls 35
Quercus chrysolepis	Maul oak	Pacific states	Bark 7–12
Quercus coccifera	Kermes oak	Mediterranean	Bark 10–18
Quercus coccinea	Scarlet oak	United States	Bark 8
Quercus densiflora	Tanbark oak	California	Bark 10–29
Quercus dentata	Japanese oak	Japan	Bark 11 Wood 7
Quercus fenestrata		Northern India	Bark 10–16
Quercus garryana	Pacific post oak	Pacific states	Bark 6–7
Quercus grosseserrata	Water oak	Japan	Bark 9 Wood 2
Quercus ilex	Evergreen oak	Southern Europe	Bark 5–11
Quercus incana		India	Bark 22
Quercus infectoria	Aleppo	Turkey	Galls 24–60
Quercus lamellosa		Northern India	Bark 8–10
Quercus lineata		Northern India	Bark 11
Quercus lobata	White oak	California	Bark 12
Quercus mirbechi		Algeria	Bark 8
Quercus pachyphylla	Sungra katus	Northern India	Acorn cups 13–15 Bark 12–13 Leaves 10
Quercus prinus	Chestnut oak	United States	Bark 9–12
Quercus pseudocornea	Gie-quang	Indo-China	Bark 16
Quercus robur	Common oak	Europe and U. S.	Bark 9–12 Wood 2–4
Quercus rubra	Red oak	Northern America	Twig galls 35 Bark 4–6
Quercus spp	Gie-bob	Indo-China	Bark 11
Quercus suber	Cork oak	Europe	Bark 12–19
Quercus tozae		Southern France	Bark 14
Quercus velutina	Black oak	United States	Bark 6–12
Quercus wislizeni	Highland oak	California	Bark 7–8
Rheedia braziliensis	Pakuri	Paraguay	Bark 22
Rhizophora conjugata	Mangrove	Philippines	Bark 26–32
Rhizophora mangle	Mangrove	Tropical coasts	Bark 15–42 Leaves 22
Rhizophora mucronata	Mangrove	Asia and Africa	Bark 21–48
Rhus copallina	Sumac	United States	Leaves 17–38
Rhus coriaria	Sicilian sumac	Sicily	Leaves 25–32
Rhus cotinus	Venetian sumac	Italy	Leaves 17
Rhus cotinoides	Sumac	United States	Leaves 21
Rhus glabra	White sumac	United States	Leaves 15–25
Rhus metopium	Sumac	United States	Leaves 8
Rhus mysorensis		Southern India	Bark 20
Rhus pentaphylla	Tizra sumac	Morocco	Roots 29 Wood 23
Rhus rhodanthema	Deep yellow wood	New South Wales	Bark 23
Rhus semialata	Sumac	America and Asia	Leaves 5 Chinese galls 70

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Rhus succedanea	Sumac	India	Leaves 20
Rhus thunbergii		Cape Good Hope	Bark 28
Rhus typhina	Virginian sumac	Virginia	Leaves 10–18
Robinia pseudacacia	Black locust	Europe	Bark 2–7 Wood 3–4
Rollinia sp	Aratiku gwazu	Paraguay	Bark 4
Rumex hymenosepalum	Canaigre	Mexico	Roots 25–30
Rumex maritima	Docks	Europe	Roots 22
Sabal palmetto	Cabbage palmetto	Florida	Roots 10–18
Sabal serrulata	Saw palmetto	Florida	Leaves 13
Salix alba	White willow		Bark 9
Salix arenaria	Willow	Russia	Bark 13
Salix caproea	Willow	Japan	Bark 8–12
Salix fragilis	Willow		Bark 9–12
Salix lasiandra	Yellow willow	California	Bark 2
Salix purpurea	Willow	Japan	Bark 8
Salix viminalis	Willow	Russia	Bark 7–10
Schinus molle	Molle	Argentina	Leaves 19
Sequoia sempervirens	Redwood	Pacific states	Heartwood 4–12 Sapwood 1–2 Bark 1–3
Shorea obtusa		India	Bark 9 Wood 6–7
Shorea robusta	Sal bark	India	Bark 6–15
Sonneratia pagatpat	Pagatpat	Philippines	Bark 11–12
Spermolepsis gummifera	Oak gum	New Caledonia	Bark 17 Resin 43–80
Statice coriaria	Marsh rosemary	Southern Russia	Roots 20–22
Stryphnodendron barbatimao	Barbatimao	Brazil	Bark 18–27
Tamarix africana	Tamarisk	Mediterranean	Galls 26–56 Twigs 9 Leaves 9
Tamarix articulata	Tamarisk	Morocco	Galls 43–56
Tamarix dioica	Jhao	India	Bark 10
Taxus cuspidata	Yew	Japan	Bark 10
Terminalia arjuna	Kahua	India	Bark 18–24
Terminalia belerica	Bedda	India	Nuts 12
Terminalia catappa	Badamier	India	Bark 12–25
Terminalia chebula	Myrobalan	India	Nuts 30–40
Terminalia glabra	Kumbuk	Ceylon	Bark 27–32
Terminalia mauritiana	Jamrosa	India	Bark 30
Terminalia oliveri	Thann	Malay	Bark 31 Leaves 14
Tormentilla erecta		Europe	Roots 20–46
Trichilia catigua	Kaatigua puihta	Paraguay	Bark 21
Trichilia hieronymi	Kaatigua moroti	Paraguay	Bark 23
Tsuga canadensis	Hemlock	Northern America	Bark 7–12
Tsuga heterophylla	Western hemlock	Pacific states	Bark 9–16
Umbellularia californica	California laurel	California	Bark 16
Vateria indica		India	Fruit 25
Weimannia glabra	Curtidor	Venezuela	Bark 10–13
Woodfordia floribunda	Itcha	India	Bark 27 Leaves 15
Ximenia americana	Alimu	Sudan	Bark 17
Xylia dolabriformis	Jamba	Burma and India	Bark 9–19 Wood 4
Xylocarpus granatum	Piagao	Africa and Asia	Bark 21–48
Xylocarpus obovatus	Tabique	Philippines	Bark 22–25
Zizyphus nummularia	Ber	India	Bark 10
Zizyphus xylopyra	Gothar	India	Fruit flesh 23

LITERATURE

(For a key to the periodicals see end of volume)

The following periodicals, reports and books were used in the above compilation: *45*; *54*; *157*; *257*; *258*; *259*; *260*; *261*; *262*; *263*; *264*; *265*; *Reports*, Freiberg Experiment Station; *Reports*, Australian Institute of Science and Industry; U. S. Department of Commerce, *Reports*; H. R. Procter, *Principles of Leather Manufacture*, New York, 1922; J. Dekker, *Die Gerbstoffe*, Berlin, 1913; A. Harvey, *Tanning Materials*, London, 1921; J. A. Wilson, *The Chemistry of Leather Manufacture*, New York, 1923.

Electrical Potential Difference (P. D.) between Tannin Particles and Solutions of Tanning Extracts

1. Extracts from Different Sources

Extract of	Concn. g dry solids per l	P. D. (volts)
Gambier	18.7	−0.005
Oak bark	17.0	−0.009
Chestnut wood	17.8	−0.009
Hemlock bark	16.7	−0.010
Sumac leaves	19.6	−0.014
Spruce bark	19.5	−0.018
Osage orange wood	13.7	−0.018 (?)
Quebracho wood	11.0	−0.028

2. Effect of Removal of Nontannin by Dialysis

Extract of	Initial concn. g dry solids per l	Hours dialyzed	Final concn. g dry solids per l	P. D. (volts)
Gambier	32.8	24	21.0	−0.029
Hemlock bark		24		−0.024
Sumac leaves	16.0	24	8.6	−0.026
Osage orange	16.0	24	10.9	−0.024
Quebracho wood	16.0	60	9.6	−0.033

3. Effect of Concentration of Quebracho Extract

Concn. g dry solids per l	P. D. (volts)
4.0	−0.030
8.0	−0.029
16.0	−0.028
32.0	−0.024

4. Effect of Addition of Acid

(16 g solid quebracho extract per l)

0.1N HCl added per l	P. D. (volts)
0.0	−0.024
10.0	−0.014
15.0	−0.010
20.0	approx. zero

LITERATURE

Thomas and Foster, *45*, **14**: 191; 22. **15**: 707; 23.

LEATHER

John Arthur Wilson

Ind. No.	Type	Genres de cuirs	Die untersuchten Lederarten	Tipi di pelle
1.	Colored, vegetable-tanned calf.	Veau teint, tanné au végétal.	Farbiges lohgares Kalbleder.	Vitello al tannino, colorato.
2.	Colored, chrome-tanned calf.	Veau teint, tanné au chrôme.	Farbiges Chromkalbleder.	Vitello al cromo, colorato.
3.	Black, chrome-tanned, glazed kid.	Chevreau verni, noir, tanné au chrôme.	Schwarzes Chromchevreaux.	Cuoio morbido di montone; glacé tinto in nero al cromo.
4.	Black, chrome-tanned kangaroo.	Kangourou noir, tanné au chrôme.	Schwarzes chromgares Känguruhleder.	Pelle di canguro al cromo, tinta in nero.
5.	Black, vegetable-tanned horse butt (Cordovan).	Croupon de cheval, tanné au végétal (Cordovan).	Schwarzer lohgare Rosspiegel (Cordovan).	Culatta di cavallo al tannino tinta in nero (Cordovano).
6.	Colored, chrome-tanned, buffed and split cow hide (buck).	Cuir de vache teint, tanné au chrôme, refendu et effleuré (façon daim).	Farbige chromgare, gebuffte Rindernarbenspalte (buck).	Pelle di vacca al cromo, spaccata, scamosciata, colorata.
7.	Colored, chrome-tanned side (split cow hide).	Bande entière de vache (refendue) teinte, tannée au chrôme.	Farbige chromgare Rindspalte.	Fianco di vacca (spaccata) al cromo, colorato.

8. Black, chrome-tanned slink calf (suede).	Veau mort-né noir, tanné au chrôme (façon suède).	Schwarzes chromgare Kalbleder (suède).	Pelle di vitello (feto) al cromo, tinta in nero (tipo svedese).
9. Uncolored, vegetable-tanned calf (shoe lining).	Veau naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgare Kalbleder (Schuhfutterleder).	Vitello al tannino in color naturale (fodera da calzature).
10. Uncolored, vegetable-tanned sheep (shoe lining).	Mouton naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgare Schafleder (Schuhfutterleder).	Montone al tannino in color naturale (fodera da calzature).
11. Black, vegetable-tanned shark.	Requin noir, tanné au végétal.	Schwarzeslohgare Haifischleder.	Pelle di squalo al tannino, tinta in nero.
12. Patent, chrome-tanned side (split cow hide).	Bande entière de vache (refendue), vernie, tannée au chrôme.	Chromgares Rindspaltlackleder.	Fianco di vacca (spaccata) al cromo, brevettato.
13. Patent, chrome-tanned kid.	Chevreau verni, tanné au chrôme.	Chromchevreauxlackleder.	Cuoio morbido di montone al cromo, brevettato.
14. Patent, chrome-tanned colt.	Poulain verni, tanné au chrôme.	Chromgares Rosslackleder.	Puledro al cromo, brevettato.
15. Heavy, black, chrome-tanned cow hide.	Cuir de vache, fort, noir, tanné au chrôme.	Schweres schwarzes Chromrindleder.	Pelle di vacca al cromo tinta in nero, pesante.
16. Chrome-re-tan, army upper leather (split cow hide).	Cuir d'empeigne pour l'armée, semi-chrôme (peau de vache refendue chrômé, puis retanné au végétal).	Nachchromiertes Militäroberleder (Rindspalte).	Cuoio di vacca (spaccata) superiore per l'esercito, riconciato al cromo.
17. Vegetable-tanned steer hide (sole leather).	Cuir de génisse, tanné au végétal (cuir de semelles).	Lohgares Rindleder (Sohlenleder).	Pelle di giovenco al tannino (cuoio da suola).
18. Chrome-tanned steer hide (sole leather).	Cuir de génisse, tanné au chrôme (cuir de semelles).	Chromgares Rindleder (Sohlenleder).	Pelle di giovenco al cromo (cuoio da suola).

Each analysis was made on one representative skin of each type. The same 18 skins were used to make all measurements listed in this section, thus making all properties of any one type directly comparable and related to chemical composition.

Chaque analyse a été effectuée sur une peau représentative de chaque genre de cuir. On a utilisé les mêmes 18 peaux pour faire toutes les mesures mentionnées dans cette section. De la sorte, toutes les propriétés de chaque genre de cuir sont directement comparables et en relation avec la composition chimique.

Jede Analyse wurde an einem besonderem Vertreter einer Hauttype gemacht. Dieselben 18 Häute sind für alle Messungen die in diesem Abschnitt angeführt werden, verwendet worden. Eswerdendadurchalle Eigenschaften jeder einzelnen Type direkt vergleichbar und in Beziehung zur chemischen Zusammensetzung gebracht.

Ogni analisi fu fatta sopra un campione rappresentante ciascun tipo di pelle. Gli stessi 18 campioni furono usati per eseguire tutte le misure indicate in questa sezione, risultando così tutte le proprietà di ogni singolo tipo direttamente paragonabili ed in rapporto alla composizione chimica.

Composition, % at 50% Relative Humidity (1)

Ind. No.	H_2O	Skin protein	Fat	H_2SO_4	Na_2SO_4	HCl	NaCl	CaO	$MgSO_4$	Al_2O_3	Fe_2O_3	Cr_2O_3	Organic water soluble	Collodion	Combined tannin by diff.	Other organic matter by diff.
1	13.6	41.0	12.0	0.3						0.4	0.1		9.1		23.5	
2	16.3	62.6	4.6	3.4	0.4	0.3	0.5			1.2	0.3	5.4				5.0
3	13.7	65.3	6.6	1.0	0.9	0.5	0.2	0.2		0.2	0.3	4.5				6.6
4	12.0	62.7	11.3	1.8	0.2	0.3	0.1	0.3		0.1	0.1	6.0				5.1
5	10.0	40.1	18.6	0.6				0.1			0.1		8.7		21.8	
6	14.1	69.6	2.1	3.2	0.3			0.2		1.0	0.6	5.3				3.6
7	16.3	66.8	5.8	3.6	1.0		0.3	0.1		0.2	0.2	3.6				2.1
8	12.7	55.1	7.1	0.8	0.4	0.2	0.1	0.2		1.0	1.2	5.4				15.8
9	11.9	46.0	7.6	0.1				0.2		0.1			12.3		21.8	
10	10.9	50.0	6.1	1.7		0.6		0.1		0.1	0.1		13.0		17.4	
11	12.2	45.4	6.9	1.5				0.1			0.1		5.4		28.4	
12	10.1	50.5	10.0	1.8	0.6	0.1		0.1		0.1	0.4	2.9		9.0		14.4
13	11.8	54.0	6.6	2.1	0.3			0.2		0.2	0.6	3.6		8.4		12.2
14	12.0	60.4	5.1	2.3	0.5	0.1	0.1	0.3		0.1	0.3	3.6		6.1		9.1
15	14.4	57.0	14.2	4.4	0.4	0.1	0.4				0.7	5.5				2.9
16	15.1	44.6	20.4	1.1	0.3		0.4	$CaSO_4$		0.3	0.2	2.4				15.2
17	14.6	29.7	3.2	0.8					0.8		0.7		35.6		14.6	
18	16.3	29.4	25.4	5.9	12.3	0.8	0.9	2.3	0.5	2.6	0.5	1.7				1.4

Tensile Strength, Stretch and Stitch Tear (1)

Each value recorded is the average of 3 determinations. The strips for strength and stretch were cut with a die 2.54 × 15.24 cm and the jaws of the testing machine were initially 10.16 cm apart. The 3 strips from each skin were cut with their lengths parallel to the backbone and spaced equally between head and tail end along a line midway between backbone and belly edge. The leather was in equilibrium with an atmosphere of 50% relative humidity. The stitch tear was made with Irish flax shoe thread No. 6 slipped through a hole 2 mm from the leather edge.

l = average thickness; TS = tensile strength in kg per cm² of original cross section; S = stretch (a) at 13.6 kg per 2.54 cm width, (b) at 225 kg per cm²; ST = stitch tear.

Ind. No.	l mm	TS kg/cm²	% S (a)	% S (b)	ST kg
1	1.19	422	5	17	13
2	1.00	327	7	22	10
3	0.76	409	20	34	8
4	0.52	508	16	24	9
5	1.12	113	14	53	7
6	0.92	201	9	34	5
7	1.22	213	11	36	10
8	0.63	156	19	36	1
9	0.93	310	11	27	8
10	0.87	200	13	35	6
11	0.80	118	35	84	5
12	1.09	90	10	69	3
13	0.96	217	17	42	7
14	1.43	228	13	46	8
15	2.94	182	8	54	27
16	2.48	346	6	29	28
17	6.28	191	1	23	38
18	4.80	100	1	70	21

Area Change with Relative Humidity

Measurements were made after 30 days contact at 25°C. The samples were kept in desiccators over sulfuric acid solutions of 37.5, 17.6, 13.6, 11.8, 10.2, 6.6, and 0.0 normalities to maintain the relative humidities at 0, 20, 40, 50, 60, 80 and 100% respectively.

Ind. No.	% increase in area with increasing relative humidity					
	Relative humidity					
	20	40	50	60	80	100
1	3.6	4.2	4.5	4.8	5.5	5.7
2	7.7	10.0	10.3	11.5	12.4	16.0
3	3.4	4.6	4.8	5.5	7.5	15.6
4	5.7	6.9	6.9	7.5	10.9	19.0
5	2.0	3.0	3.0	3.2	3.4	4.0
6	6.7	7.5	7.7	8.8	10.5	14.7
7	6.7	7.7	8.0	9.2	10.5	15.8
8	8.0	10.7	10.9	11.7	11.9	13.8
9	5.3	6.5	6.7	6.9	7.5	9.2
10	4.2	5.5	5.5	5.9	8.2	9.4
11	4.0	4.9	5.1	5.3	5.7	8.0
12	5.5	6.3	6.3	6.9	8.6	10.5
13	5.3	5.9	6.1	6.5	7.1	9.6
14	4.5	6.3	6.3	6.5	8.2	13.0
15	7.1	8.0	8.0	9.2	10.9	16.9
16	6.5	7.7	8.0	8.4	9.0	11.5
17	1.0	1.4	2.7	3.0	3.0	5.5
18	3.8	4.5	5.9	6.3	7.7	13.0

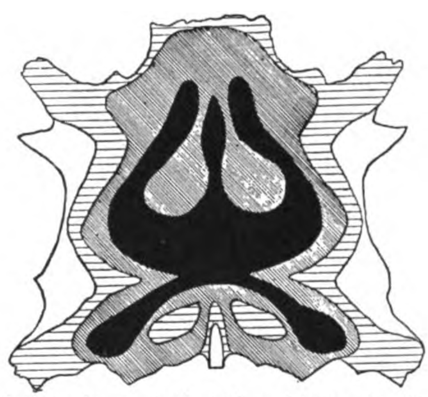


FIG. 1.—Variations in strength and resistance to stretch for calf leather from different parts of the skin (3).

Tensile strength given in kg per cm^2.
Percentage stretch measured under load of 225 kg per cm^2.

Tensile strength less than 170 kg. Stretch greater than 60 %.
Tensile strength 170 to 260 kg. Stretch 60 to 26 %.
Tensile strength 260 to 350 kg. Stretch 26 to 20 %.
Tensile strength greater than 350 kg. Stretch less than 20 %.

Water Content at Different Relative Humidities (1, 2)

Ind. No.	g water per 100 g dry leather after 30 days at relative humidity of %						
	0	20	40	50	60	80	100
1	1.4	10.8	14.0	15.7	17.9	21.2	39.6
2	2.1	12.4	18.1	19.5	21.0	27.9	53.4
3	2.9	10.6	14.2	15.9	18.1	27.3	62.2
4	0.4	9.3	12.6	13.6	15.4	22.8	51.7
5	1.8	7.0	9.8	11.1	11.8	15.6	22.9
6	2.2	11.7	15.4	16.4	17.4	25.1	47.8
7	1.8	12.1	17.2	19.5	20.8	25.9	54.5
8	0.3	9.4	13.4	14.5	15.8	20.9	59.5

Water Content at Different Relative Humidities (1, 2).—(*Continued*)

Ind. No.	g water per 100 g dry leather after 30 days at relative humidity of %						
	0	20	40	50	60	80	100
9	0.9	8.8	12.1	13.5	16.1	19.6	32.0
10	1.1	8.2	11.3	12.2	14.6	19.6	48.4
11	2.4	10.2	12.7	13.9	14.3	17.1	38.1
12	0.7	8.5	10.4	11.2	12.6	18.5	36.9
13	1.9	10.5	12.7	13.4	14.6	20.7	39.5
14	2.0	9.6	12.4	13.6	15.1	22.7	57.5
15	1.2	12.9	15.1	16.8	17.7	21.9	49.6
16	4.4	12.5	16.4	17.8	18.4	21.1	37.8
17	3.4	12.2	17.0	17.1	18.3	21.7	43.6
18	8.6	14.9	18.1	19.5	20.6	24.5	50.4

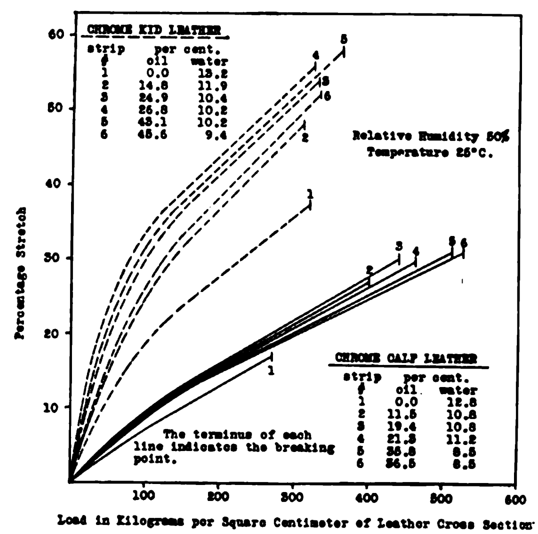


FIG. 2.—Effect of oil content (4).

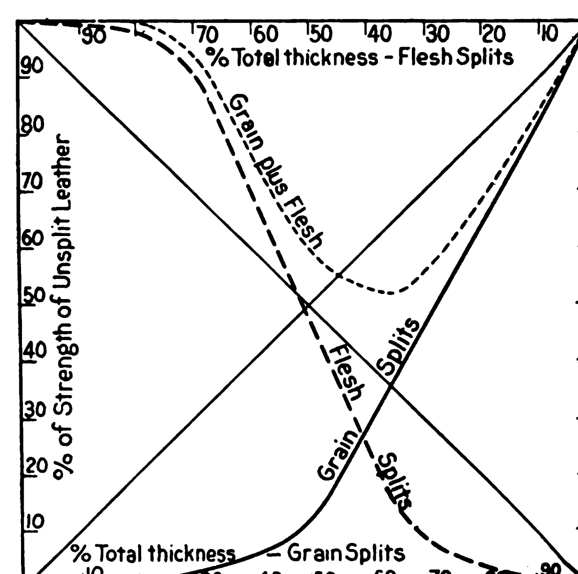


FIG. 3.—Relative strengths of splits of vegetable-tanned calf leather compared with unsplit leather. Average tensile strength of skin 324 kg/cm^2; average thickness 0.91 mm. Strengths in chart are given per unit width, not cross section (5).

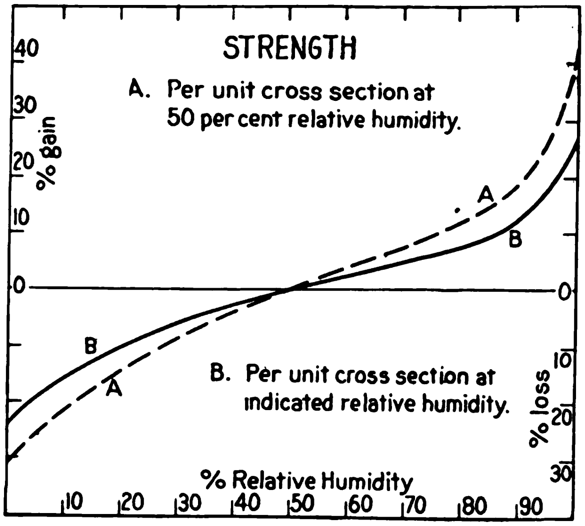


FIG. 4.—Percentage gain or loss in strength per unit cross section of chrome calf leather with change of relative humidity. The difference between the two curves reflects the volume change in the leather with relative humidity. Leather with high fat content shows much less change in strength with relative humidity (8).

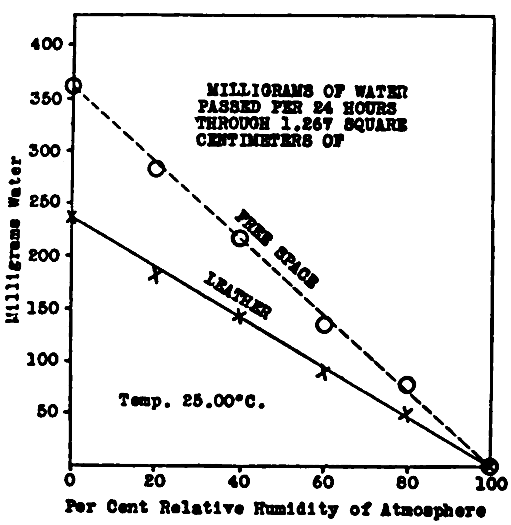


FIG. 5.—Effect of relative humidity of 1 atmosphere upon passage of water into it from an atmosphere kept at 100 % relative humidity through vegetable-tanned calf leather and through free space (6).

VENTILATING PROPERTIES

Effect of kind of skin and tannage (1)

Ind. No.	1	2	3	4	5	6	7	8	9
1 mm.	1.08	1.00	0.73	0.53	1.15	0.88	1.22	0.60	0.88
P_W*, %	70	70	70	65	54	95	74	97	79
P_A†	197	67	249	185	41	1183	369	1820	246

Ind. No.	10	11	12	13	14	15	16	17	18
1 mm.	0.88	0.89	1.01	0.99	1.37	2.59	2.31	6.28	4.80
P_W*, %	78	89	6	9	5	38	49	34	4
P_A†	251	1416	0	0	0	45	179	43	0

* P_W, % permeability to water vapor, is defined as 100 times the ratio of the rate of passage of water from an atmosphere of 100 % relative humidity to one of zero humidity through a given area of the leather sample, of thickness, 1, to the rate of a similar passage of water through an equal area of free space at the same temperature. In these measurements, the area chosen was 1.267 cm^2 and the temperature 25°C.

† P_A, permeability to air, is defined as the rate of flow of air (cm^3/min per cm^2 of leather) through thickness 1, under the pressure difference, atmospheric to 35 mm Hg.

Effect of temperature, Fig. 6; effect of relative humidity, Fig. 5.

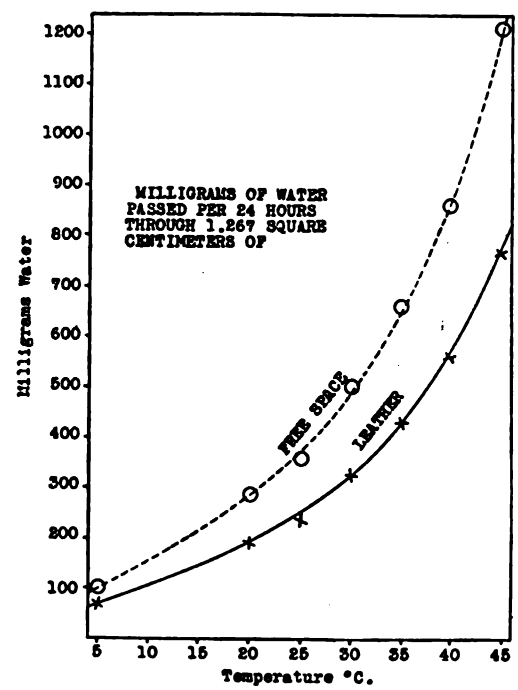


FIG. 6.—Effect of temperature upon passage of water from an atmosphere of 100 % relative humidity to one of zero relative humidity through vegetable-tanned calf leather and through free space (6).

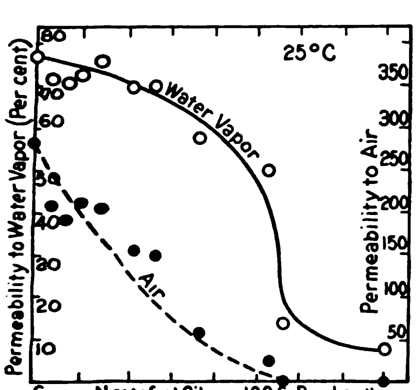


FIG. 7.—Effect of oil content of leather (6).

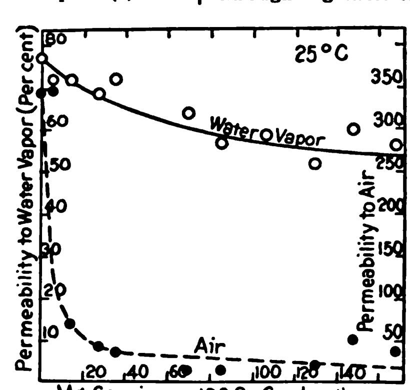


FIG. 8.—Effect of quantity of casein used as finishing material (6).

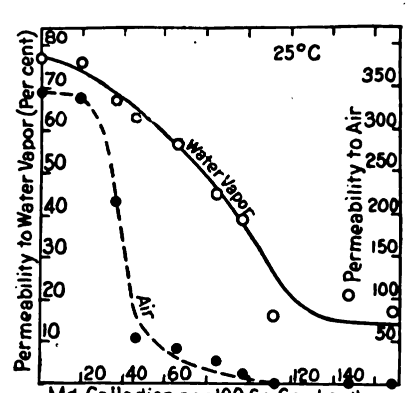


FIG. 9.—Effect of quantity of collodion used as finishing material (6).

Relative resilience is defined as the percentage rebound of a brass plunger (weighing 48.5 g and having a contact area of 0.70 cm^2) when dropped from a height of 60 cm upon a thickness of 3 mm of leather backed by a solid maple block. Relative humidity 50%.

The relative resilience is decreased by an increasing content of either water or oil.

RESILIENCE (1, 7)

Ind. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rel. resilience	22	26	28	24	16	23	21	21	22	21	23	19	22	23	17	11	39	17

LITERATURE

(For a key to the periodicals see end of volume)

(1) Wilson *et. al.*, *261*, **21**: 193, 198, 241; 26. (2) Wilson and Gallun, *45*, **16**: 268; 24. (3) Wilson, *45*, **17**: 829; 25. (4) Wilson and Gallun, *45*, **16**: 1147; 24. (5) Wilson and Kern, *45*, **18**: 312; 26. (6) Wilson and Lines, *45*, **17**: 570; 25. (7) Wilson, *261*, **20**: 576; 25. (8) Wilson and Kern, *261*, **21**: 250; 26.

RUBBER, GUTTA-PERCHA AND BALATA

G. STAFFORD WHITBY

ABBREVIATIONS

T_B Breaking load expressed unless otherwise stated as kg per cm^2 unstrained cross section

E_B Ultimate elongation (percentage of unstrained length)

T_x Stiffness, expressed as the load (kg/cm^2 unstrained cross section) required to produce an increase in length x times the unstrained length

E_T Stiffness, expressed as the percentage elongation produced by a load T kg/cm^2 unstrained cross section

V. C. Vulcanization coefficient

D_{30} Plasticity expressed as the thickness of a disc (0.4 g) after 30 min in a Williams' plastometer at 100° under a load of 5 kg

ΔD Plasticity expressed as D_{25}–D_{35}

Cure Unless otherwise indicated, the period of vulcanization required to give an optimum or standard "cure."

η Viscosity, expressed unless otherwise indicated as the time of flow of a 1% solution in benzene relative to the time of flow of the pure solvent.

LATEX

Specific Gravity

Average Undiluted Latex.—0.97 to 0.98 ([197]).

Serum from Normal Latex.—1.016 to 1.025 ([197]).

Globules in Latex.—0.914 ([181]).

TABLE 1.—VARIATION WITH RUBBER CONTENT OF ORIGINAL UNDILUTED LATEX ([197])

g rubber/100 cm³	50	45	40	35	30
d_4^t	0.9620	0.9678	0.9736	0.9794	0.9852
g rubber/100 cm³	25	20	17	15	10
d_4^t	0.9910	0.9968	1.0003	1.0026	1.0084

TABLE 2.—TEMPERATURE COEFFICIENT OF SPECIFIC GRAVITY OF LATEX ([81])

Sp. gr.	0.9950	0.9900	0.9850	0.9800	0.9750
Corr. 1°	0.00030	0.00034	0.00038	0.00042	0.00046

Viscosity

TABLE 3.—VISCOSITY OF ORIGINAL LATEX WITH AND WITHOUT NH_3 ([191])

% rubber content		35	30	25	20	15
η/η_w at 30°	Without NH_3	12–15	8	5–6	4	
	With NH_3*		4–5.5	3–4	2.5	2

* Viscosity falls on keeping.

TABLE 4.—INFLUENCE OF DILUTION ON VISCOSITY OF AMMONIATED LATEX ([94])

Ratio		% solids	d_4^{20}	200 cm³ in Engler viscosimeter	
Latex	Water			Sec	Deg. Engler
5	0	48.5	0.963	110	2.1
4	1	37.5	0.972	75	1.42
2.5	2.5	24.25	0.981	65	1.23
2	3	18.7	0.983	60	1.15
1	4	9.4	0.992	50	1.0

Surface Tension ([10])

Drop No.—(*a*) water, 31; (*b*) latex diluted with equal volume of water, 37 to 40; (*c*) 2% NH_3, 37 to 38; (*d*) *c* after 2 months, 49 to 50.

Miscellaneous

Fresh Latex.—pH: 5.8 to 6.4 ([10]), 6.2 to 6.6 ([20]); acidity: 0.02 to 0.04*N* (phenolphthalein) ([190]); alkalinity: 0.002 to 0.008*N* (methyl red) ([190]).

Potential Difference between Surface of Particles and Surrounding Liquid (*Ammoniated Latex*).— −35 millivolts ([145]).

Size and Shape of Globules ([19, 66, 225]).

Rubber Content

TABLE 5.—DISTRIBUTION OF RUBBER CONTENT IN LATEX FROM 245 7-YR OLD TREES ([211])

Mean: 36.58 ± 0.25%

g/100 cm³	23	24–5	26–7	28–9	30–1	32–3	34–5	36–7
Number of trees	4	2	7	11	16	27	44	35

g/100 cm³	38–9	40–1	42–3	44–5	46–7	48–9	50–1	52–3	54–5
Number of trees	23	12	17	12	5	1	4	3	2

Influence of severity of tapping ([181]) and of resting trees ([179, 181]) on rubber content of latex; *cf.* Tables 7, 8.

Chemical Composition

Acetaldehyde in Latex.—0.006 g/l ([91]). Trace of NH_3 present ([91]).

Heat-Coagulable Protein in Serum.—After coagulation by acetic acid, 0.15% (rubber content of latex, 40%) ([11]); 0.115% ([203]); after coagulation by alcohol, 0.19% ([203]).

TABLE 6

Component \ Sample	a([7])	b([7])	c([7])	d([130])	e([71])
Total solids	30.0	22.0	25.8	32.4	
Rubber by coagulation				29.0	37.0
Solids in serum				3.4	2.91
Solids in dialysate	2.6	1.65	1.54	3.2	
Protein (non-diffusible, N × 6.25)	1.26	0.87	1.04		
Diffusible N:					
Total	0.048	0.054	0.043	0.072	
Ammoniacal				0.0096	

Total N (mean of 3 samples): 0.29 for f([11]).

Dialysates from samples a, b, c (mean values)

	Sugars*	Ash	SO_3	P_2O_5	CaO	MgO	K_2O
% latex	0.18	0.31	0.008	0.09	0.01	0.016	0.17
% ash			2.6	29.1	3.2	5.2	54.8

* After inversion.

Serum solids from sample e, NH_3 also present

	Ash	Protein (N × 6.25)	Sugars	Quebrachitol
g/100 cm³	0.53	0.34	0.25	1.45

Deposit Which Forms in Ammoniated Latex

Composition of deposit (*ca.* 0 to 7% of the latex) ([37]), %: Of this deposit *ca.* 30% is volatile in steam in the presence of MgO.

	Sample 3*	Sample 5*
Rubber	*ca.* 30	*ca.* 30
Acetone extract	11.6	6.4
N insol. in Me_2CO	2.4	1.6
Fe_2O_3	9.0	15.1
MgO	16.0	13.1
P_2O_5	28.0	23.6
K_2SO_4	Tr.	Tr.

* *See* Table 9.

Deposit consisting of NH_4MgPO_4, 0.3 to 1.1 g/l ([190]).

Oxidases

Present.—Peroxidase (the chief oxidase; fatal temperature, 80 to 85°); oxidase; catalase; tyrosinase (fatal temperature, 70°). Optimum pH, 4.65 to 4.95, using citrate buffer solution; 8.13 to 8.28, using borax buffer solution. Inhibitory pH, 1.03; very sensitive to alkali ([21]).

Activators.—Ca and Mg salts ([21, 207]).

TABLE 7.—RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM UNDER DIFFERENT TAPPING SYSTEMS ([203])

Tapping system	1 cut on $\frac{1}{3}$	2 cuts on $\frac{1}{4}$	2 cuts on $\frac{1}{2}$	2 cuts on $\frac{3}{4}$	2 cuts on $\frac{1}{1}$
Rubber content*	34.2	31.65	28.2	22.75	22.4
Solid content†	8.8	9.5	10.1	8.6	11.6

* g/100 cm³ by coagulation. † Expressed on rubber %.

TABLE 8.—INFLUENCE OF RESTING TREES ON RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM ([6])

Days after tapping began following long rest	1	3	12	18	22	33
Rubber content by coagulation (%)	43.0	39.3	31.5	35.8	21.8	14.8
Serum solids (% of rubber)	4.9	7.1	10.15	13.2	13.8	16.9

Ammoniated Latex

0.33% NH_3 will preserve latex in liquid condition, while 0.5%, giving an alkalinity of 0.25*N* (methyl red), is absolutely reliable ([190]).

Table 9.—Coagulation of Ammoniated Latex in Europe [37]

Sample	Rubber content, %	NH_3 content (% rubber) Added (in Ceylon)	Found (In Europe)	% CH_3CO_2H*
1	33.2	0.89	0.82	4.4
2	33.0	1.19	1.00	4.46
3	32.5	1.80	1.57	8.75
4	31.8	2.40	2.17	12.2
5	32.6	2.92	2.73	15.8

* Per cent of acetic acid necessary for coagulation in excess of the acid equivalent to the NH_3 present.

Table 10.—Vulcanizing Properties of Rubber by CH_3CO_2H Coagulation from Latex Preserved with Different Proportions of NH_3 [37]

Pure gum mixture (ring-shaped test pieces)

Sample, *cf.* Table 9	Cure, min	T_B	E_B	E_{104}	Slope
1	115	164	855	777	35
2	130	157	859	781	36
3	126	144	842	786	37
4	125	147	840	771	36
5	125	164	874	784	36

Table 11.—Influence of Age of Ammoniated Latex on Vulcanizing Properties of Rubber [201]

Undiluted latex containing 0.72% NH_3; coagulated by CH_3CO_2H; stock: rubber, 92.5; S, 7.5%; vulcanized at 148°

	Aqueous extract, %	Acetone extract, %	Cure, min	T_B	η Orig.	After 14 mo	Orig. in acid C_6H_6
Control	0.44	3.0	110	128	31	29	16
Ammoniated:							
Same day	0.37	2.9	90	135	31	30	15.5
Next day	0.54	3.2	70	143	27	30	17
After 1 mo	0.23	3.2	105	143	53	22.5	19
After 3 mo	0.22	3.9	100	124	56	28	18

Table 12.—Ammoniated Latex Creamed by Centrifugation [129]

Stock: rubber, 92.5; S, 7.5; vulcanized for 90 min at 147°; coagulated by CH_3CO_2H

	Composition of rubber by evaporation, % Rubber	H_2O	Acetone extract	Ash	Protein	Aqueous extract	S*
Orig. latex	17.6	2.0	2.3	1.0	4.0	3.4	4.7
Cream	48.0	0.6	1.8	0.4	1.8	0.4	3.9
Skimmed latex	9.7	4.1	2.9	2.0	7.4	13.1	5.2

* Per cent combined S.

Latex with NaOH

0.5 to 1% NaOH will preserve latex in a liquid condition; 1.3% or more causes the separation of a paste or coagulation, the resulting rubber being of poor quality and becoming tacky on keeping [198].

Table 13.—Influence of Age of NaOH Latex on Rubber (Crepe) by CH_3CO_2H Coagulation [198]

Stock: rubber, 92.5; S, 7.5; vulcanized at 148° (ring-shaped test pieces)

Period after addition	Ash, %	Aqueous extract, %	Acetone extract, %	N, %	Cure, min	T_B	Slope	η
Control*	0.40	1.11	2.6	0.55	<35	133	39.5	24.5
Same day	0.31	0.37	3.0	0.52	<45	145	40	33
Next day	0.29	0.21	3.1	0.43	80	122	36.5	40.5
1.5 mo	0.40	0.28	3.7	0.42	60	122	37	36
3.5 mo	0.46	0.30	2.9	0.38	50	137	33	31
6 mo	0.34	0.38	3.4	0.50	110	132	38.5	33

* Same day, no NaOH.

Table 14.—Rubber from Creamed NaOH Latex [198]

Latex containing 1.1% NaOH allowed to stand 2 yr; layers coagulated by CH_3CO_2H; crepe; stock: rubber, 92.5; S, 7.5; vulcanized at 148°.

	Cream	2nd layer	3rd layer	4th layer	Residue
% rubber content	62.8	50.0	45.8	26.8	4.4
% H_2O	0.67	0.95	1.72	1.66	1.68
% ash	0.55	0.58	0.65	0.73	1.22
% N	0.09	0.10	0.13	0.18	0.48
Cure, min	55	45	>25	35	
T_B	130	135	130	120	
Slope	34	34	34	34	
η (ordin.)	13	30	41	48	78
η (acid)	7	15	17.5	18.5	26
Plasticity:					
D_{30}	0.88	1.15	1.36	1.29	1.16
ΔD	0.085	0.11	0.08	0.10	0.11

Vulcanization of Latex

Table 15.—Influence of Period of Vulcanization and of Character of the S on the Combined S [43]

Composition of mixture: 100 cm³ latex; 50 cm³ H_2O; 2 g S (rubber coagulated by acetone). Latex No. 1: rubber, 32.9%; NH_3, 0.6%. Latex No. 2: rubber, 30.15%; NH_3, 0.43%. Vulcanizing conditions: rise to 141°, 10 min; blow-off, 20 min.

Time at 141°, min	Combined sulfur, % Latex No. 1 Flowers	Latex No. 2 Flowers	Pptd.	Colloidal
0	0.18	0.13	0.23	0.47
20	0.59		0.85	1.56
30		0.46	1.04	1.87
60	0.91	0.55	1.47	2.44
120	1.07			2.64

Table 16.—Influence of Concentration of S [43]

Composition of mixture: 100 cm³ latex (30.7% rubber; 0.43% NH_3); 50 cm³ H_2O; 1% S (calculated on rubber + S). Vulcanizing conditions: 10 min rise; 30 min at 141°; 20 min at blow-off.

S g	% on rubber	Comb. S, %	E_{60} (films)
1	3.26	0.64	1000
2	6.51	1.02	954
4	13.02	1.42	951
6	19.53	1.65	886

Table 17.—Vulcanization with Sodium Polysulfide [43]

Composition of mixture: 120 cm³ latex (32.9% rubber, 0.6% NH_3); 10 cm³ sodium polysulfide (21.0% S on pptn.). Vulcanizing conditions: 10 min rise to 141°; 20 min blow-off.

Period at 141°, min	0	20	30	60	120
Combined S, %	0.31	0.85	1.02	1.42	1.88

Coagulation

Acidity Necessary for Coagulation.—By addition of acid, pH = 4.3 to 4.8 [10, 20]. By addition of acid to ammoniated latex (dialyzed or undialyzed), pH *ca.* 5.5 [103]. For spontaneous coagulation, pH = 4.8 to 5.6 [20].

CH_3CO_2H, ACETIC ACID

Table 18.—Proportion of CH_3CO_2H Used in Plantation Practice [189]

Rubber	15%		25%	
For coagulation on	Same day	Next day	Same day	Next day
CH_3CO_2H (g/l)	1–1.25	0.75	1.5	1

TABLE 19.—CONCENTRATION OF CH_3CO_2H REQUIRED TO COAGULATE LATEX DILUTED TO DIFFERENT EXTENTS (189), *cf.* (188)

% rubber content	Ratio, acid:rubber	% rubber content	Ratio, acid:rubber
30	1:303	6	1:83.5
24	1:190	3	1:91
18	1:115	1.5	1:125
15	1:100	0.75	1:83.5
12	1:89		

Influence of excess CH_3CO_2H on properties of crepe: Double the minimum quantity increases time of cure 0 to 5 min; decreases viscosity 0 to 4. Four times minimum quantity increases time of cure 5 to 10 min for the stock: rubber, 92.5; S, 7.5, at 148°; decreases viscosity 2 to 7 (176).

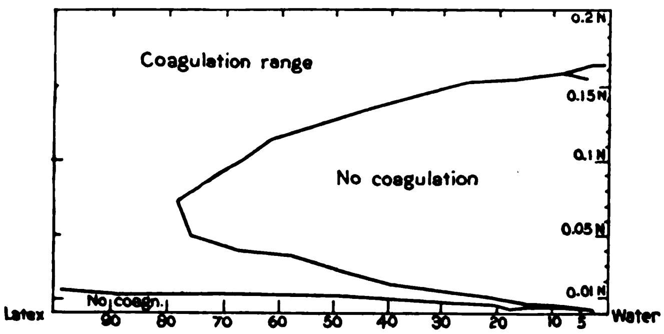


FIG. 1.—Concentrations of hydrochloric acid producing coagulation in latex (31.8% rubber, *ca.* 35% total solids) diluted to different extents (188).

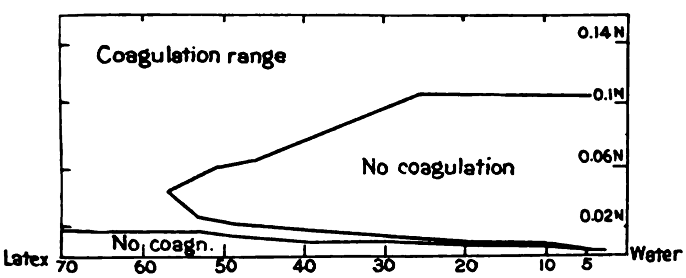


FIG. 2.—Concentrations of nitric acid producing coagulation in latex (28% rubber) diluted to different extents (188).

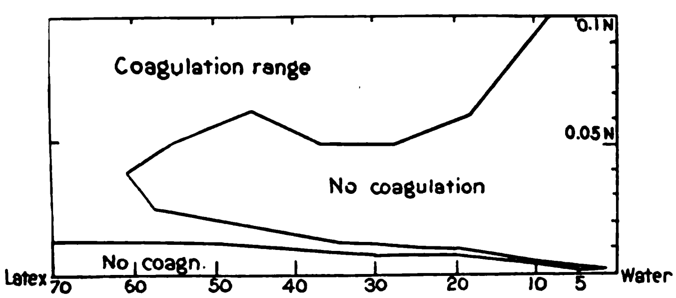


FIG. 3.—Concentrations of sulfuric acid producing coagulation in latex (28% rubber) diluted to different extents (188).

H_2SO_4, SULFURIC ACID

Proportion H_2SO_4 Used in Practice.—0.45 to 0.6 g/l latex (15% rubber).

TABLE 20.—VULCANIZING PROPERTIES OF CREPE RUBBER PREPARED BY H_2SO_4 (182)

Stock: rubber, 92.5; S, 7.5; vulcanized at 148° (ring-shaped test pieces)

Normal proportion				Double the normal proportion			
Cure, min	T_B	Slope	η	Cure, min	T_B	Slope	η
125	140	38	35	150	136	38.5	27

ALUM

Minimum Effective Proportions.—3 to 4 g/l.

TABLE 21.—EFFECT OF ALUM (COMPARED WITH CH_3CO_2H) ON PROPERTIES OF CREPE (182)

Alum (g/l)	3–4	10	20
Increase in time of cure, min	∢15	∢30	∢85
Decrease in viscosity	4–7	7–12	10–12

HCO_2H, FORMIC ACID

The proportion of HCO_2H necessary for coagulation is about half the quantity of CH_3CO_2H (130); *cf.* Tables 18, 19.

TABLE 22.—COMPARISON OF HCO_2H AND CH_3CO_2H (101)

Stock: rubber, 92.5; S, 7.5 %; vulcanized at 150° (ring-shaped test pieces, 11 samples)

Description	Cure, min	T_B	Slope	η
Smoked sheet:				
CH_3CO_2H	105	143	36.7	31
HCO_2H	109	141.5	36.7	35.5
Pale crepe:				
CH_3CO_2H	110	143.5	35.6	33
HCO_2H	113	143	35.5	33

Stock: rubber, 100; S, 3; ZnO, 30; $(CH_2)_6N_4$, hexamethylenetetramine, 1; vulcanized at 150° (ring-shaped test pieces)

Vulcanization time in min	T_B	E_B	E_{130}	T_B	E_B	E_{130}
	Smoked sheet, CH_3CO_2H			Smoked sheet, HCO_2H		
40	185	784	693	173	784	714
50	173	751	678	173	766	695
60	176	763	688	174	769	693
70	146	738	712	167	763	698
80	146	772	748	131	764	762
	Pale crepe, CH_3CO_2H			Pale crepe, HCO_2H		
40	165	803	750	168	811	752
50	182	785	712	179	776	708
60	176	778	714	179	782	714
70	167	765	714	168	771	717
80	157	779	738	151	776	743

Stock: rubber, 100; S, 5; PbO, 10; vulcanized at 150° (ring-shaped test pieces)

Vulcanization time in min	T_B	E_B	E_{100}	T_B	E_B	E_{100}
	Smoked sheet, CH_3CO_2H			Smoked sheet, HCO_2H		
30	106	895	883	102	905	900
60	106	944	932	100	935	935
90	97	989	997	87	977	1000
120	79	1000	1056	84	1014	1060
	Pale crepe, CH_3CO_2H			Pale crepe, HCO_2H		
30	125	931	887	118	923	891
60	124	977	933	119	964	929
90	105	1014	1003	105	1006	995
120	94	1027	1042	99	1039	1040

TABLE 23.—CHEMICAL COMPOSITION, %

	H_2O	Ash	Water extract	Acetone extract	N
Smoked sheet, CH_3CO_2H	0.75	0.35	0.75	3.4	0.49
Smoked sheet, HCO_2H.	0.72	0.30	0.58	3.4	0.47
Pale crepe, CH_3CO_2H..	0.33	0.23	0.16	3.0	0.36
Pale crepe, HCO_2H.....	0.37	0.17	0.21	3.0	0.36

TABLE 24.—AGING

Raw crepe rubber

	Cure, min	T_B	Slope	η		Plasticity	
				C_6H_6	$HCl + C_6H_6$	D_{30}	ΔD
Initial, CH_3CO_2H.	110	141	34	32	17	1.52	0.065
Initial, HCO_2H...	<120	134	35	31	16.5	1.41	0.07
After 1 yr, CH_3CO_2H......	120	141	35	27	16.5	1.58	0.07
After 1 yr, HCO_2H	>120	145	35	26	16.5	1.58	0.06

TABLE 24.—AGING.—(*Continued*)

Vulcanized rubber; stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Cure, min	T_B		Change in E_{130}
	Initial	After 1 yr	
75, CH_3CO_2H..........	86	119	*ca.* 170
75, HCO_2H............	86	118	*ca.* 170
120, CH_3CO_2H..........	133	17	
120, HCO_2H............	140	16	

OTHER COAGULANTS

Hydrofluoric (57), citric (57), oxalic (57), tartaric (57), lactic (202), sulfurous acids (178); calcium chloride (208); alcohol (40); pyroligneous acid (58); freezing (58); electrolysis (187).

CHEMICAL COMPOSITION OF RAW RUBBER

TABLE 25.—COMPOSITION OF HEVEA RUBBERS

	Number of samples	H_2O, %		Ash, %		Acetone extract, %		Protein, % (N × 6.25)		Water extract, %	Lit.
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits		
Latex crepe.............	102	0.61	0.30–1.08	0.30	0.15–0.87	2.88	2.26–3.45	2.82	2.17–3.76		(130)
Smoked sheet............	35	0.42	0.18–0.90	0.38	0.25–0.85	2.89	1.52–3.50	2.82	2.18–3.50		(130)
Unsmoked sheet.........	25	0.58	0.32–1.30*	0.23	0.15–0.31	2.88	2.30–3.47	2.31	2.04–2.68		(35)
Fine hard Para..........				0.3		3		2.3		0.5	(183)
				1.10		4.25		4.2		6.50	(86)
Latex sprayed...........				1.5		4.7		4.2		7.1	(158)
		1.2		1.5		5.1		4.3		7.7	(128)
Kerbosch rubber.........			2.5–4.5		1.6–2.2	2.2		5.0		1.5	(194)
		4.2		1.9		2.5		4.5		4.1	(128)

* % loss on washing.

TABLE 26.—MOISTURE CONTENT OF RAW RUBBER

	Number of samples	Moisture content, %	
		Mean	Limits
In the tropics (177)			
Latex crepe....................	54	0.67	0.34–1.01
Smoked sheet..................	96	0.76	0.43–1.16
Lump crepe....................	17	1.05	0.65–1.80
Scum or skimmings crepe.......	3	0.43	0.35–0.53
Washings crepe................	6	0.55	0.27–0.78
Scrap crepe....................	15	1.16	0.68–1.64
Dark crepe.....................	3	1.07	0.90–1.33
Earth crepe....................	2	0.70	0.60–0.81
In Europe (130)			
Latex crepe....................	102	0.42	0.18–0.90
Smoked sheet..................	35	0.61	0.30–1.08
Fine hard Para, washed and air-dried.......................			0.56
Caucho........................			0.31

TABLE 27.—RESIN CONTENT

Hevea.—*v.* Table 29.

Castilloa, %.—16.7, 18.9 (130); 5.4–52 (17 samples) (26).

Ceara (*Manicoba*), %.—3.4, 6.8 (130); 2.0 (206).

Congo, %.—2.0, 4.4, 5.2 (130).

Kassai, Red.—3.8 (206).

Kassai, Black.—4.0 (206).

Jelutong.—76–81 (3 samples) (55).

TABLE 28.—OPTICAL ACTIVITY OF RESIN FROM VARIOUS RUBBERS (85)

Source	$[\alpha]_D^{20}$	Source	$[\alpha]_D^{20}$
Upper Congo.........	12–13°	Padang.............	28–30°
Manaos.............	16–18°	Guayule.............	11–15°
Peruvian............	29–31°	Kassai..............	29–30°
Jelutong............	49–50°		

TABLE 29.—SAPONIFIABILITY (130)

Rubber	Resin, %	Unsaponifiable, %	
		Of the rubber	Of the resin
Fine hard Para............	3.0	0.8	25.4
Hevea sheet...............	1.8	0.9	48.3
Hevea crepe...............	3.2	0.7	22.0
Castilloa..................	18.9	14.0	73.7
Congo.....................	4.4	3.0	68.3
Jelutong..................	38.1	31.7	83.2
Jelutong crepe............	7.2	5.6	77.8

TABLE 30.—NITROGENOUS CONSTITUENTS

Average N content of crepe and sheet, 0.45%; of slab, 0.21–0.30% (57).

A sample of crepe contained 0.40% N, representing 61.5% of the total N (0.11%) of the latex (57).

Properties of Rubber Proteins.—*v.* (11, 12, 150).

Nitrogen in Acetone Extract.—Crepe (2 samples), 0.04; sheet, 0.014; fine hard Para, 0.053; Manicoba, 0.069; Manihot, 0.041; Castilloa, 0.027; hard Congo, 0.013; soft Congo, 0.15% (130).

TABLE 31.—CONSTITUENTS IDENTIFIED IN THE RESIN OF HEVEA RUBBER

Constituent	M. P., °C	$[\alpha]_D^t$	Approximate % of the raw rubber
Smoked sheet and latex crepe (215)*			
Phytosterol ester.....	83	−11.0° (24°)	0.075
Sitosterol *d*-glucoside.	285–90 d	−41.7° (23°)	0.175
Phytosterol..........	125	−24.6° (23.5°)	0.225
d-Valine.............	*ca.* 260 d	26.5° (16°)	0.015
Quebrachitol.........	190	−80.3° (20°)	Tr.
Stearic acid..........			0.15
Oleic + linoleic acids.			1.25

* In slab (matured) rubber (28) acetic and valeric acids have been identified (probably as the NH_4 salt or amide); also valeramide, M. P. 102–3°, and palmitic and stearic acids (0.5–0.7 %).

TABLE 32.—ACID CONTENT

Water-soluble acids* by cold extraction for 24 hr (130)

Sheet				Crepe			
Number of samples	Mean	Maximum	Minimum	Number of samples	Mean	Maximum	Minimum
35	0.03	0.078	0.006	102	0.006	0.024	0.006

* Results expressed as % acetic acid.

By extraction with boiling water (8, 50, 136). Pale crepe, 0–0.1%; smoked sheet, 0.055–0.25%.

Acetone-soluble acids

Kind of rubber	a (213, 214, 222)				b (28)			
	Number of samples	Acid number* Mean	Maximum	Minimum	Number of samples	Acid number* Mean	Maximum	Minimum
Hevea smoked sheet..	19	275	314	234		292	300	284
Hevea latex crepe....	12	282	296	272				
Fine hard Para......	12	218	384	100		215		
Hevea scrap (brown) crepe............	3	151	223	92				
Latex sprayed.......	3	453	534	301	2	273.5		
Slab (matured rubber):								
Unwashed.........					3	851	896	818
Outside.........	1	256						
Interior.........	1	459						
Washed...........	1	224			2	237.5	240	235
Palembang "plain sheet"............					3		366	336
Caucho.............	1	57						
Kassai..............	1	75						
Massai.............					2	182	182	166

c (34). Acid number:* Fine hard Para, 294; Kassai, 32; Guayule, 240; Ceara, 172; Upper Congo, 43; Benguella, 60; Peruvian, 18; Accra lumps, 75.5.

* Acid number = mg KOH required to neutralize the acid in the acetone or alcohol extract from 100 g rubber.

TABLE 33.—MANGANESE CONTENT (29)

	Number of samples	g Mn/100 kg Mean	Limits
Sound rubber (fine hard Para, sheet, crepe, slab)............	11	0.16	0.125–0.625
Very tacky rubber (sheet, brown crepe)......................	5	20.0	

PHYSICAL PROPERTIES OF RAW RUBBER

Coefficient of cubical expansion: under no load, $\frac{10^6}{V}\frac{dV}{dt}$ = at 10°, 657; 20°, 665; 30°, 670 (133). At constant length practically the same values hold as those for no load (99, 105, 133).

TABLE 34

	d_4^{20}	V_M^{20}	n_D^t	M_D
Purified rubber (106)........	0.9237		1.5219^{20}	22.46
Smoked sheet (106)..........	0.9217	73.8	1.5208^{20}	22.44
Pale crepe (164), *cf.* (42).....			1.525^{15}	
Synthetic methyl rubber (106)	0.9292	88.23	1.525^{20}	27.03

Viscosity of Raw Rubber and Its Solutions

RUBBER

TABLE 34A

Unmilled.—ca. 10^{20} poise at 15.5° (1). (By extrapolation from values for solutions.)

Milled (77).

Period of milling, min.....	10	22	32	39
10^{-7} η at 100°...........	9.3	5.0	3.2	2.4

Heavily Milled.—η = 22.4 × 10^5 at 10°; 2.29 × 10^5 at 60° (1).

UNMILLED RUBBER SOLUTIONS

Ostwald viscosimeter used unless otherwise indicated

TABLE 35.—CASTILLOA RUBBER (65)

Number of samples	Resin content, %	Relative viscosity in benzene 0.25% Mean	Limits	0.5% Mean	Limits	1.0% Mean	Limits
13	18.9–37.0	3.0	2.0–3.5	6.7	3.5–9.0	26.0	9.2–36.5

For viscosity of 1 % solution in benzene of typical samples of Hevea rubber *v.* Tables 49, 57, 58.

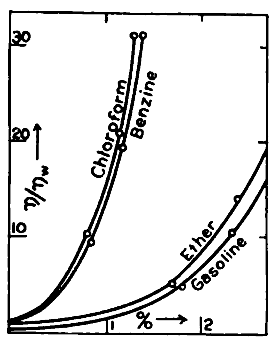


FIG. 4.—Viscosity of plantation rubber in various solvents (67).

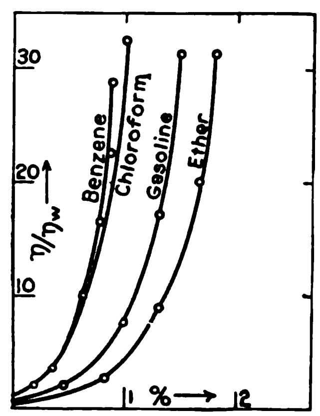


FIG. 5.—Viscosity of fine hard Para rubber in various solvents (67).

TABLE 36.—CONCENTRATED SOLUTIONS IN BENZENE (1)

Falling sphere method

Concentration, %.......	2	3	4	5	6
η at 15°, poise...........	5.04	35.63	162.8	464.4	1577

TABLE 37.—ONE PER CENT SOLUTION IN CHLOROFORM (113)

	Number of samples	η/η_0 at 25°, centipoise Mean	Limits
Pale crepe................	5	32.7	22.5–41.6
Smoked sheet.............	12	22.9	16.3–26.6

Table 38.—Comparison of Viscosity in C_6H_6, C_7H_8 and CCl_4 (130)

Extreme samples in a series of 5 samples

Solvent	Sample No. 1			Sample No. 5		
	C_6H_6	C_7H_8	CCl_4	C_6H_6	C_7H_8	CCl_4
Concn	0.998	0.998	0.997	0.993	0.991	0.993
η/η_0	20.26	20.94	29.95	53.5	68.1	119.5
$\eta/\eta_{C_6H_6\ soln}$	1.00	1.04	1.48		1.29	2.24

Table 39.—Viscosity in Various Solvents at Various Concentrations (92)

Solvent \ g/100 cm³ solvent	0.5	1	2	3
Benzine	1.9	4.3		94.0
Benzene	2.1	4.7	23.5	97.3
Carbon tetrachloride	2.6	7.5		211.3
Tetrachloroethane	2.5	6.9		168
Pentachloroethane	3.0	8.7	46.0	213.5

Variations of viscosity with concentration: (1) $\eta_x = k^x$, where η_x = the viscosity at concentration x; k = a constant (67). (2) $\log \eta/\eta_0 = \theta C$, where η = viscosity of solution, η_0 = viscosity of solvent, C = concentration (147).

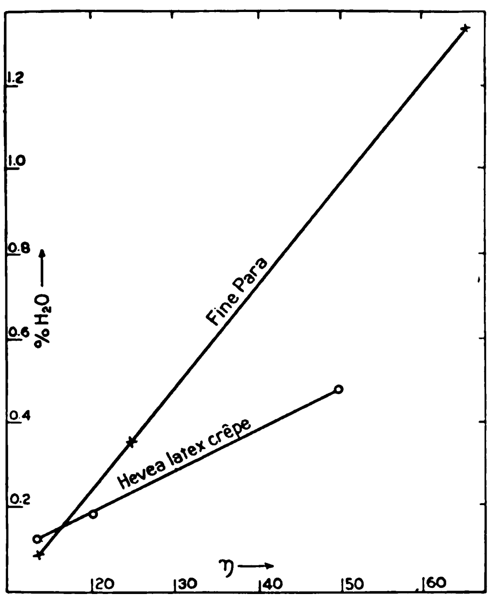


Fig. 6.—Influence of water on viscosity of benzene solutions (92).

Table 40.—Influence of Heating on Viscosity (67)

Toluene solution at 40°

Period of heating, days	0	6	12
Time of efflux, sec	260	150	129

Xylene solutions at 80°

Period of heating \ g/100 cm³	Time of efflux, sec					
	0.4	0.48	0.54	0.60	0.73	0.82
0	61.5	73.0	87.0	104.5	138.0	187.0
30 min	53.0	62.0	74.0	89.5	120.0	161.0
1 hr	51.0	60.0	70.0	81.5	111.5	148.0
2 hr	46.5	57.0	64.0	73.5	105.0	132.0
3 hr	44.0	56.0	62.0	69.0	98.0	124.5

Xylene solutions heated 2 hr at 100°

Rubber	Number of samples	Time of efflux, sec	
		Initial	After heating
Fine hard Para	3	111–103	48–46
Plantation Hevea	3	115–108	72–65
Fine hard Para (45 min in cold)	1	118	81
Funtumia	3	104–100	81–70
Castilloa	2	111, 107	80.5, 78
Ceara	1	118	90

Law of diminution of viscosity with time of heating: $x = a + b \log t$, where x = diminution in time t; a = diminution in first unit of time; b = increment of diminution with time (67).

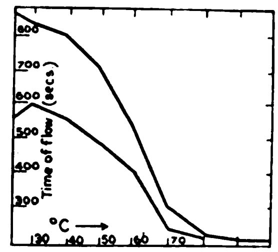


Fig. 7.—Viscosities at 18° of 0.5 % solutions in xylene of two samples of plantation rubber heated for two hours at various temperatures (13).

Table 41.—Influence of Ultra-violet Light* (13)

	Plantation					Fine Para				
Min exposed	0	15	30	45	60	0	15	30	45	60
Viscosity†	90	57	30	25	15	180	109	32	25	15

* Three per cent solution in xylene exposed at distance of 12 cm from quartz lamp (110 volts, 2.5 amp.).

† Frank-Mackwald viscosimeter.

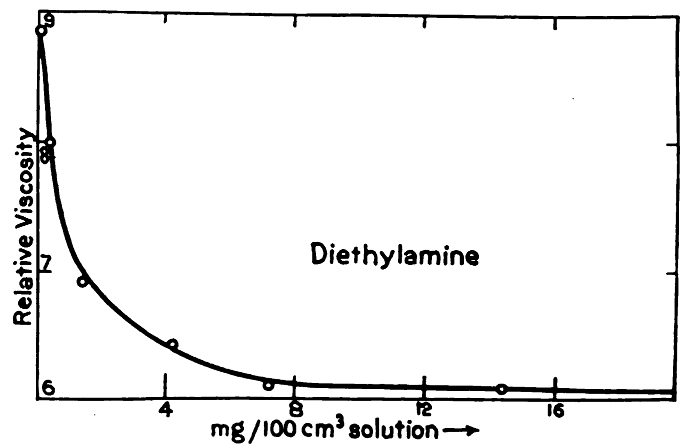


Fig. 8.—Influence of diethylamine on the viscosity of a benzene solution of rubber (218).

MILLED RUBBER SOLUTIONS

Table 42.—Influence of Milling. 2% Solution in C_6H_6 (13)

Milling period, min	25	5	10	15	20	30	40	50	60
Time of flow, sec	1900	540	150	100	90	70	65	60	59

Table 43.—Effect of Temperature on Viscosity and Density

Falling sphere method; heavily milled smoked sheet (10 g/100 cm³ solution in C_6H_6) (1)

°C	11.3	14.6	20.0	30.0	42.0	50.0	62.0
d_4^t	0.890	0.887	0.881	0.871	0.859	0.851	0.840
η*	3.97	3.77	3.42	2.92	2.57	2.32	1.95

* Expressed in poises.

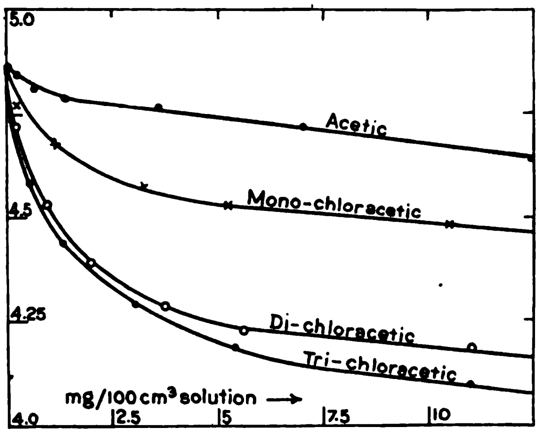


FIG. 9.—Influence of acetic and the chloroacetic acids on the viscosity of a benzene solution of resin-free rubber [218]; *cf.* [60, 150, 192].

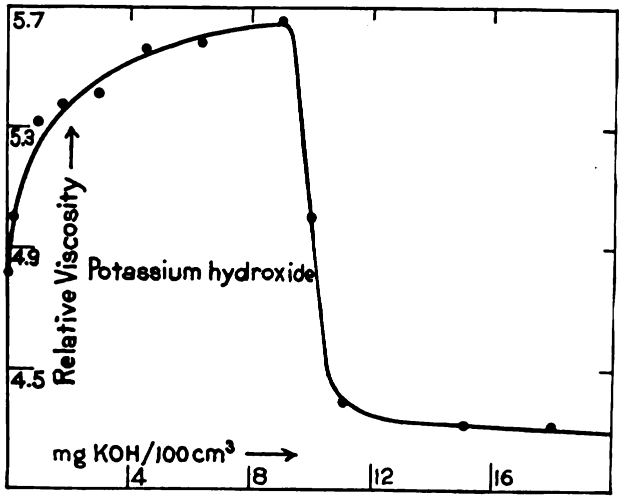


FIG. 10.—Influence of KOH on the viscosity of a benzene solution of a resin-free rubber (0.4961 g per 100 cm³) [218].

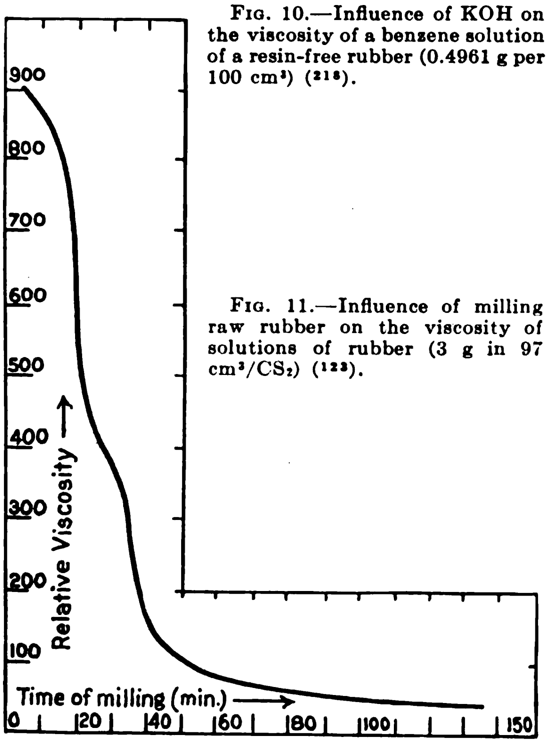


FIG. 11.—Influence of milling raw rubber on the viscosity of solutions of rubber (3 g in 97 cm^3/CS_2) [123].

TABLE 44.—VISCOSITY OF BENZENE SOLUTIONS OF HEAVILY MILLED RUBBER AT LOW CONCENTRATIONS [1]

Same sample as in Table 43 and Fig. 12

Concn	0	0.5	1.0	2.0	3.0
η, poises	0.0063	0.0124	0.021	0.055	0.131

Relation between viscosity and concentration [1]: $\eta_c = Ke^{k\sqrt{c}}$, for $c = 1 - 40$, where c = concn.; K and k are constants; e = base Naperian logs.

TABLE 45.—INFLUENCE OF LIGHT [123]

Solutions of milled rubber in benzene exposed to light through a screen of benzene: (a) 3 g/97 cm³ benzene. (b) a + 0.06 g Sudan III/100 cm³.

	(a) exposed	(b) exposed	(b) protected
Initial viscosity	548.7	548.7	548.7
After 30 days	52.5	457.0	473.2
After 60 days	30.2	339.0	393.2

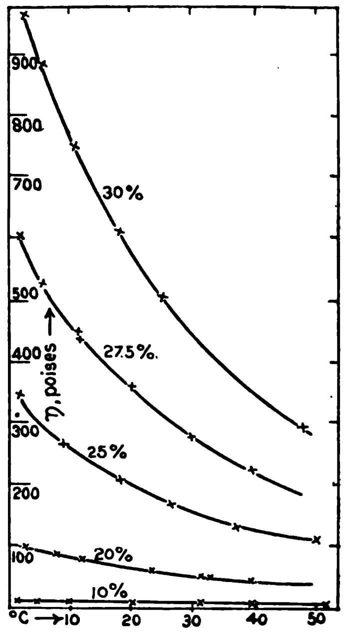


FIG. 12.—Viscosity of rubber solutions in C_6H_6; variation with temperature and concentration (falling sphere method) [1].

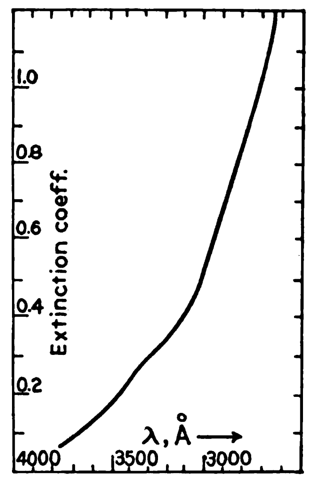


FIG. 13.—Ultra-violet absorption spectrum curve of ether solution of caoutchouc calculated on a 3 % solution in a 1 cm cell [102].

Tensile Properties

TABLE 46

At room temperature: unmilled sheet (16 samples from a single sheet), T_B: 10.4 (limits: 7.8–18.1); E_B: 527 (limits: 423–616) [130].

At low temperature: rubber calendered and then allowed to age before testing (cross section of test pieces not stated) [101].

	Crepe					Fine hard Para			
°C	−13	−21	−34	−50	−55	−13	−23	−37	−51
E_t	425	320	275	120	50			290	250
Breaking load, kg	8	20	40	40	20	3	4	40	20
E_B	530	610	670	710	570	360	280	650	705
	Fine weak Para					Congo			
°C	−14	−23	−40	−53		−15	−26	−42	−55
E_t	510	460	440	120			520	440	20
Breaking load, kg	5	20	30	16		2	5	25	20
E_B	510	700	790	610		500	520	850	640

Table 46.—(*Continued*)

At optimum temperature; E (%) for (a) crepe and (b) fine hard Para (101)

Load, kg	1	2	3	4	5	6	7	8	9
(a) at −34°	0	0	50	200	275	320	370	400	430
(b) at −37°	0	10	110	220	290	350	400	440	460
Load, kg	**10**	**12**	**14**	**16**	**18**	**20**	**25**	**30**	**40**
(a) at −34°	460	490	510	540	560	580	610	640	670
(b) at −37°	470	490	520	540	560	570	610	630	650

VARIOUS TYPES OF HEVEA

Vulcanizing Properties, Etc., of Various Types and Grades of Hevea Rubber

LATEX CREPE AND SMOKED SHEET

Table 47

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Type of rubber	Number of samples	Cure, min	T_B	Slope	η/η_0§	Lit.
Pale crepe*	1293	108.7 ± 7.6	142.4	35.4	33.5	(195)
Smoked sheet*	853	105.9 ± 12.5	143.5	36.7	33.9	(195)
Pale crepe*†	101	109.2 ± 7.2	140.8	36.0	34.7	(195)
Smoked sheet*†	149	104.6 ± 11.7	142.7	37.9	33.5	(195)
Pale crepe‡	1668	110.5	140.3	35.2	32.3	(192)
Smoked sheet‡	1647	97.5	140.7	36.4	32.6	(192)

* Prepared 1921–23. † *Ca.* 100 plantations sampled. ‡ Prepared 1917–23. § One per cent in C_6H_6.

Distribution as regards time of cure (195)

Type of rubber	Number of samples	Variation from medium value, %		
		< 10	< 20	> 20
Pale crepe	1293	83.5	99.5	0.5
Smoked sheet	853	60.5	91	9
Pale crepe	101	86	99	1
Smoked sheet	149	64.5	90	10

Stock: rubber, 90; S, 10; vulcanized at 140°. Mean for latex crepe: (cure = 195 min) T_B = 130. Mean for smoked sheet: (cure = 165 min) T_B = 146 (57).

Table 48.—Vulcanization Coefficients (110)

Data refer to a "standard" cure, *i.e.* T_{830} = 136 in the stock: rubber, 90; S, 10; vulcanized at 148°

Age of tree	10 year old trees*		20 year old trees*	
	Cure, min	V. C.	Cure, min	V. C.
Latex crepe	107	5.20 ± 0.16	126	5.00 ± 0.07
Sheet	61	5.47 ± 0.19	72	5.38 ± 0.10

* Six samples.

FINE HARD PARA

Mean Values.—Rubber, 92.5; S, 7.5; vulcanized at 150°. (Ring-shaped test pieces.) Cure (min), 100; T_B, 145; slope, 35.39; η, (1% in C_6H_6), 33 (182).

Table 50.—Comparison with Smoked Sheet from Same Latex (209)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Type	Cure, hr	T_B	E_B	Slope
Brazilian from young trees	2.25	168	929	40
Smoked sheet from young trees	1.75	158.5	928	38
Brazilian from old trees	2.25	153	919	38
Smoked sheet from old trees	2.25	149.5	944	36

CEYLON BLANKET CREPE

Table 49 (154)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Air dried mean*	Heat dried mean†	Average (17 samples) Mean	Limits	Thin crepe (for comparison) Mean	Limits
Thickness, mm			11	4–22		
Moisture, %			0.4	0.24–0.62	0.6	0.35–1.0
Ash, %			0.2	0.12–0.33		
Vulcanization time in min	124	132	129	115–140	109	
T_B	146	140	142		142	
Slope	34	35.5	35	34–36	35.5	
η, 1% in C_6H_6‡	37	23	29	21–44	34	
η, 1% in acid C_6H_6‡	20	15	17	14.5–21.5		

* 6 samples. † 9 samples. ‡ Rate of flow compared with rate of flow of the solvent.

SLAB (MATURED RUBBER)

Table 51 (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Thickness	Number of samples	% loss on washing	Cure, min	T_B	Slope
3 cm	11	22.0	35	155	32.2
1–1.5 cm	4	21.6	36	157	31.5

For stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces); cure, 75 min; T_B = 151 (mean values) (57).

Table 52.—Variation in Time of Cure (Compared with Crepe and Sheet) (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150°

Type	Cure, min		% deviation	
	Mean	Limits	Maximum	Mean
Slab (193 samples)*	35.5	15–57	118	18.8
1920–1924 samples of:				
Pale crepe	108.2	80–135	51	6.66
Smoked sheet	103.9	65–150	78	11.62

* By CH_3CO_2H and natural coagulation.

LATEX SPRAYED RUBBER

Comparison with sheet and crepe

Table 53 (86)

Stock: rubber, 100; S, 10; at 141°

Type	Number of samples	Cure, min	T_B
Latex sprayed	20	127	251
Smoked sheet	20	165	230
Latex crepe	20	183	227

Table 54 (38)

Stock: rubber, 90; S, 10; at 148° (ring-shaped test pieces); cure giving load-strain curve passing approx. through E_{775} = 104

Type	Number of samples	Cure, min	T_B	E_B	Slope
Latex sprayed	6	60	157.5	863	39
Smoked sheet	5	107	171	867	40
Latex crepe	5	136	155.5	854	37

TABLE 55 ([38])

Stock: rubber, 90; ZnO, 90; S, 10; hexamethylenetetramine, 1

Type and number of samples	Cure giving: Load-strain curve through E_{480} = 104			Maximum breaking load		
	Min	T_B	E_B	Min	T_B	E_B
Latex sprayed, 3	23	184	607	47	193	392
Smoked sheet, 5	37	175	604	45	193	458
Latex crepe, 5	42	184	624	45	187	478

TABLE 56.—PLASTICITY OF UNMILLED LATEX SPRAYED RUBBER

Number of samples	D_{30}	ΔD	η, 1% in C_6H_6	η, 1% in HCl + C_6H_6	Lit.
6	1.94	0.08	*ca.* 40	17	([196])

OTHER TYPES LATEX RUBBER

Unsmoked Sheet.—Differs from smoked sheet only in vulcanizing in about 10% less time ([183]).

Evaporated Latex.—Time of cure, 70 to 75% that of crepe ([203]); 75 min in stock: rubber, 90; S, 10; at 141° ([56]).

Kerbosch Rubber.—Time of cure, 50 to 60 min in stock: rubber, 92.5; S, 7.5; at 150° ([194]). Deteriorates on aging.

TABLE 57.—LOWER PLANTATION GRADES ([183])

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Samples washed crepe	Cure, min: Mean	Cure, min: Limits	T_B: Mean	T_B: Limits	Slope: Mean	Slope: Limits	η, 1% in C_6H_6: Mean	η, 1% in C_6H_6: Limits
Lump (naturally coagulated clots)	90	104.5	7–130	133	107–150	37.3	33.5–40	30.5	10–58
Scum or skimmings (from tanks, etc.)	30	112.5	85–135	134	124–142	36.8	34 –40	28.5	20–59
Washings (diluted latex from cups, etc.)	25	118	95–145	127	106–145	39.1	35.5–46	22.6	15–31
Tree scrap	90	105	70–185	125	104–146	38.8	35.5–44.5	25.7	13–48
Bark scrap	25	111	90–140	108	82–136	42.9	38 –47.5	19.5	11–33
Earth rubber	28	97.5	70–130	126	106–138	37.6	34 –40	20.1	15–28

TABLE 58.—NATIVE RUBBER ([155])

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Number of samples	% ash: Mean	% ash: Limits	Cure, min: Mean	Cure, min: Limits	T_B: Mean	T_B: Limits	η, 1% in C_6H_6: Mean	η, 1% in C_6H_6: Limits	η, 1% in HC + C_6H_6: Mean	η, 1% in HC + C_6H_6: Limits
Crepe prepared in laboratory from native slab*	253			96	40–160	138		24.5		12.5	
Amber crepe prepared in native factories†	14	1.01	0.2–1.8	114	100–130	130	110–153	20	11–64	11	7–25
Amber crepe prepared from native rubber in Singapore	20	0.82	0.5–1.2	93	70–140	140	125–157	20	5–48		
First quality plantation latex crepe (for comparison)			0.2–0.4	107	80–130	143		33			

* Per cent washing loss = 10–50 (limits). † Plasticity: D_{30} = 1.30 (mean), 1.0–1.72 (limits); ΔD = 0.07 (mean), 0.04–0.13 (limits).

FACTORS IN THE PREPARATION OF HEVEA RUBBER

TABLE 59.—INFLUENCE OF DILUTION OF LATEX ON THE PROPERTIES OF RUBBER ([192])

Ring-shaped test pieces

	Cure, min	T_B	Slope	η*
Undiluted latex				
Crepe milled same day	103.5	140	37.2	23.9
Crepe milled next day	84.5	142.5	36.7	27.2
Smoked sheet rolled next day	69	149	37.8	28.6
Diluted to 15% rubber content				
Crepe milled same day	113.5	138.5	37.7	25.4
Crepe milled next day	100.5	140.5	38.0	23.6
Smoked sheet rolled next day	80	144.5	37.1	31.0

* One per cent in C_6H_6.

TABLE 60.—INFLUENCE OF AGE OF TREES ON PROPERTIES ([192])

Ring-shaped test pieces

	Age, yr	Crepe: Time, min	Crepe: T_B	Sheet: Time, min	Sheet: T_B
First group of trees	3	77	123	59	127
	4.5	82	129	58	134
	7.5	97	138	64	145
Second group of trees	4.5	77	125	58	132.5
	8	96	137	68	144.5

Age, yr ([184])	35	19	18	8
Vulcanization of crepe, min	145	130	135	110
η, 1% in C_6H_6	50	39	41	28

TABLE 61.—INFLUENCE OF RESTING TREES (203)

Change in rubber content of latex, vulcanizing properties, viscosity (1% in C_6H_6), after a period of rest

Days*	Rubber content, %	Cure, min†				η			
		Crepe		Sheet		Crepe		Sheet	
		A‡	B§	A‡	B§	A‡	B§	A‡	B§
1–2	51.3	<125	160	115	160	36.5	31.5	42.5	38
3	49.3	125	150	<105	<160	36.5	34	44.5	38.5
7	43.2	125	150	95	145	36.5	30.5	42	37
10	40.9	110	140	<95	125	32	28	40.5	30
14	38.5	<105	130	90	130	31.5	29	33	31
18	35.0	95	130	80	<110	28	23	30.5	25.5
23	32.4	95	<120		100	23	23	32	27.5
28	30.1	<85	115	<80	<100	28	25	29.5	32.5
35	29.0	90	115	75	90	26.5	21.5	32	31.5
39–56	28.4	89	104	69	81	26.9	23.4	30.3	29.5

* Days after tapping started again. † Stock: rubber, 92.5; S, 7.5; vulcanized at 148°. ‡ A, undiluted latex. § B, latex diluted to 15% rubber content.

TABLE 62.—INFLUENCE OF LENGTH OF REST ON RATE OF CURE (204)

Period of rest, mo	½	1	2	3	4
Increased time of cure, min*	2	10	20	20	40

* For early tappings (2–6 expts.).

TABLE 63.—INFLUENCE OF ANTICOAGULANTS ON THE PROPERTIES OF RUBBER

	$NaHSO_3$*		$Na_2SO_3.7H_2O$
Lit	(186)	(186)	(185)
g/l latex	0.5–1	2	1.2
Increase in T_B	0 – 5	0– 5	0– 3
Decrease in min of cure	5 –10	10–15	5–10
Decrease in slope	1 – 1.5	1– 1.5	1– 1.5
Increase in η (1% in C_6H_6)	1.5–10	3–10	1– 2

* Proportion necessary to inhibit action of latex oxidase: 1 part in 400 to 2400 parts latex (9).

NON-HEVEA RUBBERS

TABLE 64.—VULCANIZATION OF CAUCHO BALL WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210	240
T_8	6.8	9.2	11.45	
T_B	34	46	57	62
E_B	1082	1045	1010	968

TABLE 65.—VULCANIZATION OF CAUCHO BALL WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	30	60	90	120
T_7	53.2	114	120	
T_B	130	152	138	27
E_B	861	769	737	

TABLE 66.—VULCANIZATION OF FICUS RUBBER WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210
T_7	8.5	11.3	13.6
T_B	49	68	83
E_B	1112	1102	1074

TABLE 67.—VULCANIZATION OF FICUS RUBBER WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	60	90
T_7	77.5	96
T_B	187	163
E_B	853	794

VULCANIZED RUBBER

Hot Vulcanization with Sulfur

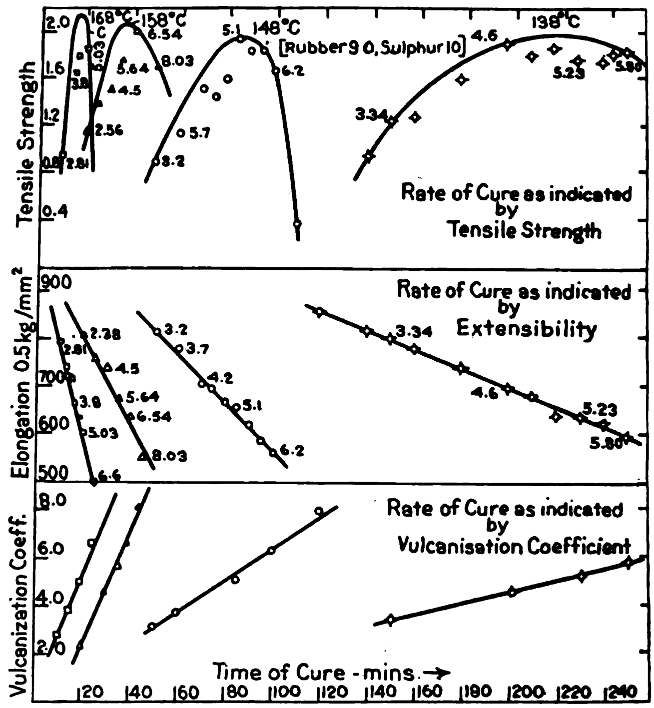


FIG. 14.—Vulcanization of simple rubber-S mixture (rubber, 90; S, 10) (165). Influence of temperature on rate of cure, ultimate tensile strength, stiffness, rate of combination of S and sharpness of tensile peak (ring-shaped test pieces).

LOAD-STRAIN RELATIONS OF VULCANIZED RUBBER

TABLE 68.—PROGRESSIVE CHANGE ON VULCANIZING A SIMPLE RUBBER-S MIXTURE

Stock: rubber, 92.5; S, 7.5, vulcanized at 148° (ring-shaped test pieces) (165)

Period vulcanized, min	T_B	Number of samples	E_B	E_{130}	V. C.
75	75 ±1.5	20	991±3.9	1110?	2.86
80	90 ±1.4	23	999±2.2	1063?	
85	102 ±1.4	29	990±2.6	1040?	3.58
90	114.5±0.8	58	992±1.4	1018	3.77
95	122 ±0.9	52	985±1.8	994	
100	131.5±0.9	39	969±1.8	966.5	4.24
105	134.5±0.8	38	957±1.9	950	4.27
110	139 ±0.8	58	944±1.6	932	4.65
115	140.5±0.7	50	928±1.5	913	4.85
120	142 ±0.6	60	916±1.0	898	5.07
125	141 ±0.8	34	901±1.5	885.5	5.30
130	139 ±0.9	28	885±1.0	771	5.49
140	137	4			
150	130	4			

TABLE 69.—MOST PROBABLE VALUES ON VULCANIZING 341 SAMPLES OF RUBBER-S MIXTURE (RUBBER, 92.5; S, 7.5) AT 148° (130), *cf.* (54, 152, 165, 175)

V. C.	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
T_4		12.4	13.9	15.4	16.9	18.4	19.9	21.4	22.9
$T_{5.5}$	34.6	47.4	60.2	73.0	85.7	98.5	111.3	132.4	148.0
T_B	64.3	77.6	91.0	104.4	119.0	128.4	138.2	137.3	115.5
E_B	965	950	930	915	910	895	890	855	800

TABLE 70.—TEMPERATURE COEFFICIENT OF HOT VULCANIZATION WITH S (165), *cf.* (54, 130, 152, 175)

	Mixture A*	Mixture B†
Temperature range	128–168°	108–148°
Temperature coefficient based on:		
Combination of S	2.3	2.3
Extensibility of vulcanizate	2.3	2.5
Tensile strength of vulcanizate	2.4	2.4

* Unaccelerated mixture: rubber, 90; S, 10.
† Accelerated mixture: rubber, 90; S, 10; aldehyde ammonia 0.125–1.0.

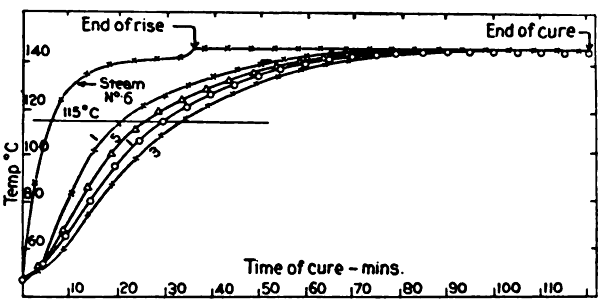


FIG. 15.—Temperature lag in vulcanization of a tire, vulcanized on air bags in steam autoclave for 2 hr at 146.3° (121). Temperatures at the following points in a 4-ply cord: (1) between second and third plies; (2) between second and third plies, under edge of the breaker; (3) same, under the center of the tread; (5) near the edge and on the top of the breaker.

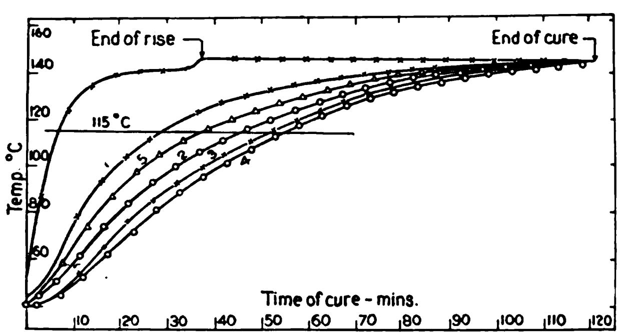


FIG. 16.—Vulcanized as in Fig. 15. Temperatures at following points in an 8-ply cover: (1) in the side between sixth and seventh plies; (2) between the sixth and seventh plies, under the edge of the breaker; (3) same, under the center of the tread; (4) same, under the edge of the breaker; (5) near the edge and on the top of the breaker.

TABLE 71.—INFLUENCE OF % OF S ON SIMPLE RUBBER-S MIXTURES

Mixtures vulcanized 90 min at 148° (130)

S, %	2.5	5	7.5	10	12.5	15	17.5	20
T_B	29	63	99	124	57	23	25	62?
E_B	900	894	894	766	431	198	183	384
V. C.	1.05	2.33	2.92	3.92	6.24	7.45	8.12	9.41

Vulcanized at 148° (199)

S, %	5	7	7.5	8	9	10
E_{50}	1200	1000	965	925	870	790
T_B	58	105	107	122	126	126
E_B	1124	1016	984	964	911	840

TABLE 72.—INFLUENCE OF % OF S ON TIME OF CURE AT 148° AND ON TENSILE PROPERTIES AT OPTIMUM CURE (199)

S, %	Min	T_B	$T_{11.25}$	E_B	E_{120}	V. C.
7.5	75	133		911	891	
6	105	135		946	924	
5	120	135		1024	1001	4.41
3	120		40	>1125		2.81

Vulcanization by Other Means

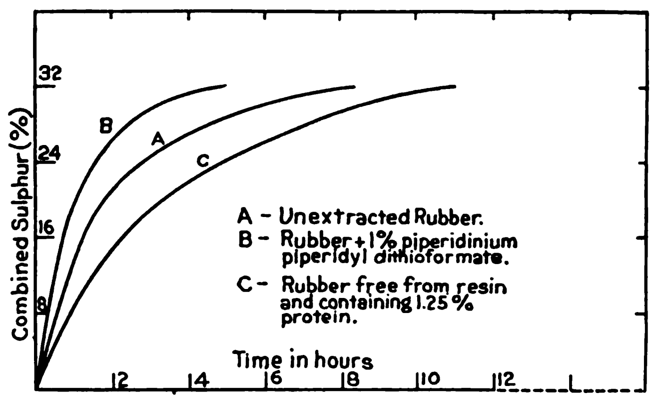


FIG. 17.—Vulcanization in solution. Rate of combination of S with (A) crepe, (B) crepe plus an accelerator and (C) crepe deprived of 52 % of its protein, on heating a 5 % solution in dichlorobenzene with 1000 % S (219); *cf.* (23, 84, 100, 157).

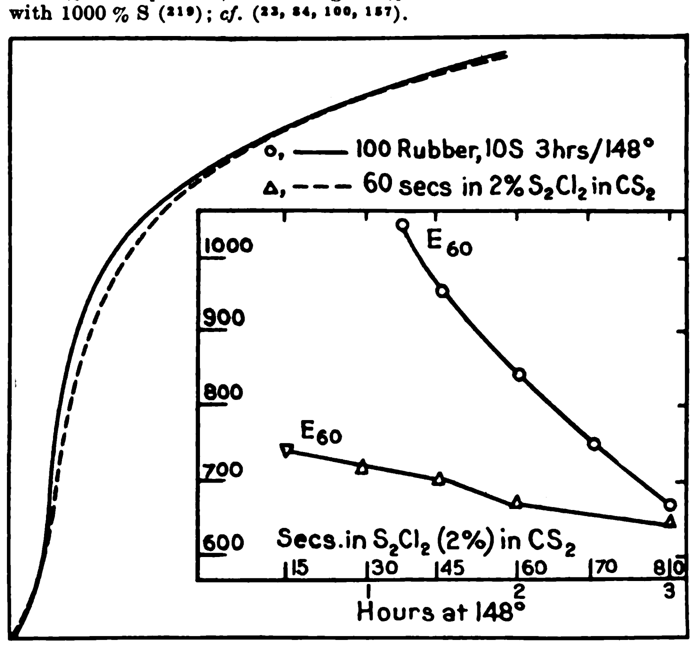


FIG. 18.—Comparison of the tensile properties (load-strain curve and stiffness) of rubber vulcanized by dipping in S_2Cl_2 solution and by heating with S (ring-shaped test pieces) (230).

SULFUR MONOCHLORIDE (130, 230)

Sheets of calendered latex crepe, 1 mm thick, dipped in solutions of S_2Cl_2 (1 − 5% in CS_2) for not more than 120 sec: T_B, 84 to 127; E_B, 800 to 1000 (ring-shaped test pieces) (230).

NITRO COMPOUNDS AND ORGANIC PEROXIDES

m-Dinitrobenzene. Stock: rubber, 100; PbO, 8; *m*-dinitrobenzene, 4; vulcanized 10 min at 147°: T_B, 103; E_B, 798 (30). Other nitro compounds and organic peroxides, *v.* (30).

TABLE 73.—MIXTURES OF SE AND S (228)

Composition of stock			Cure giving stiffest vulcanizate	
Crepe	S	Se	Time at 143°, min	T_{500}
94	6.00	0.00	270	375
94	5.11	2.19	180	430
94	4.51	3.69	210	370
94	3.73	5.6	240	315
94	0.00	14.80	No cure in 300 min	

ULTRA-VIOLET RAYS (83)

NITROGEN SULFIDE (126)

PHYSICAL PROPERTIES

Tensile Properties

FACTORS INFLUENCING TENSILE PROPERTIES

TABLE 74.—INFLUENCE OF SHAPE OF TEST PIECE AND DIRECTION OF ITS AXIS WITH REFERENCE TO THE CALENDER DIRECTION (32)

	T_B	E_B	T_B	E_B	T_B	E_B
Sample No	1		2		3	
Rings	151	635	119	675	74.5	525
Straight pieces:						
Longitudinal	192.5	630	146	640	84.5	480
Transverse	181.5	640	143.5	670	88.5	555
Sample No	4		5		6	
Rings	107	435	36	285	51.5	320
Straight pieces:						
Longitudina	130	410	48.5	320	62	315
Transverse	120	460	36	280	48.5	315

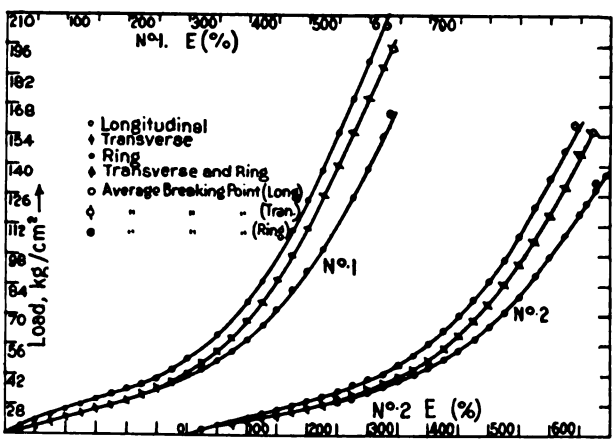


FIG. 19.—Load-strain curves of Samples 1 and 2 (Table 74) as determined by (*a*) ring test pieces, (*b*) straight test pieces cut longitudinally and (*c*) transversely (32).

TABLE 75.—INFLUENCE OF WIDTH OF STRAIGHT TEST PIECES (32)

Sample	Cover		Tube		Tube		Cover		Tube	
Width, mm	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7
T_B	110	102	151	137	72	67	51.5	48.5	175	144
E_B	525	515	580	570	350	340	335	350	615	575

TABLE 76.—INFLUENCE OF WIDTH OF RING TEST PIECES (112)
Diameter, 44.6 mm; thickness, 4 mm

	Higher-grade rubber				Lower-grade rubber			
Sample No	1		2		3		4	
Width, mm	T_B	E_B	T_B	E_B	T_B	E_B	T_B	E_B
2	158.9	808	105.8	611	18.9	182	25.2	187
4	117.7	806	97.1	624	18.8	193	27.3	203
6	97.4	809	87.5	628	17.2	183	26.0	199

TABLE 77.—INFLUENCE OF RATE OF STRETCHING (32)
Straight test pieces

Rate of jaw separation (cm/min)	12.5	60	115	12.5	60	115
	Higher-grade rubber					
Sample No	5			2		
T_B	175	188.5	190.5	133	136	138
E_B	605	635	635	465	500	490
	Lower-grade rubber					
Sample No	3			4		
T_B	26.3	30.1	32.5	23.8	27.3	30.1
E_B	340	360	375	105	115	120

TABLE 78.—INFLUENCE OF TEMPERATURE ON THE STIFFNESS OF AN ACCELERATED STOCK (47)
Stock: smoked sheet, 100; S, 3; ZnO, 6; hexamethylenetetramine, 0.9; vulcanized 60 min at 141°

t, °C	21	24	27	30
T_7	85	80	74	67

TABLE 79.—INFLUENCE OF HIGH TEMPERATURES (131)
Stock: rubber, 92.5; S, 7.5; vulcanized to various extents at 147°

	t, °C	Time of heating prior to test, min	T_B	E_B	$T_{3.5}$
Sample No. 1 (vulcanized 60 min; V. C. = 2.1)	24		63	991	31
	70	15			22
	100	15			20
	130	15			19
	147	2			19
	147	5	13	700	
	147	15	14	678	
Sample No. 2 (vulcanized 90 min; V. C. = 3.2)	26		107	990	49
	70	15	104	1049	37
	100	15	18	595	
	130	1	12	460	
	130	5	13	500	
	147	1	12	465	
	147	5	14	512	
Sample No. 3 (vulcanized 120 min; V. C. = 4.2)	23		118	914	79
	70	1	15	453	
	70	5	17	491	
	100	1	14	423	
	100	5	13	395	
	130	1	12	381	
	130	5	12	379	
	147	1	13	384	

Load-Strain Curves for Vulcanized Rubber

Independently of state of cure, the load-strain curve for rubber-S stock is a conchoid expressed by

$$y = a - b \sin \alpha \qquad (1)$$
$$x = n\,(a \cot \alpha - b \cos \alpha)$$

where x = load; y = strain; a = distance between pole and asymptote; b = distance between origin and asymptote; and n =

a constant fraction of corresponding abscissae of parent conchoid [137].

$$y = cx + a \sin^2 bx \qquad (2)$$

where y = strain; x = load; c, a, b = constants for the rubber specimen in question, characterizing respectively the initial, the middle, and the ultimate elongations [39].

$$x = A\left\{1 - \frac{2}{l - b}\right\} e^{h(p-l)^2} \qquad (3)$$

where x = load; l = length; b = breadth $\left(\text{taken as } \frac{1}{\sqrt{l}}\right)$; h, p = constants for the rubber specimen in question [118].

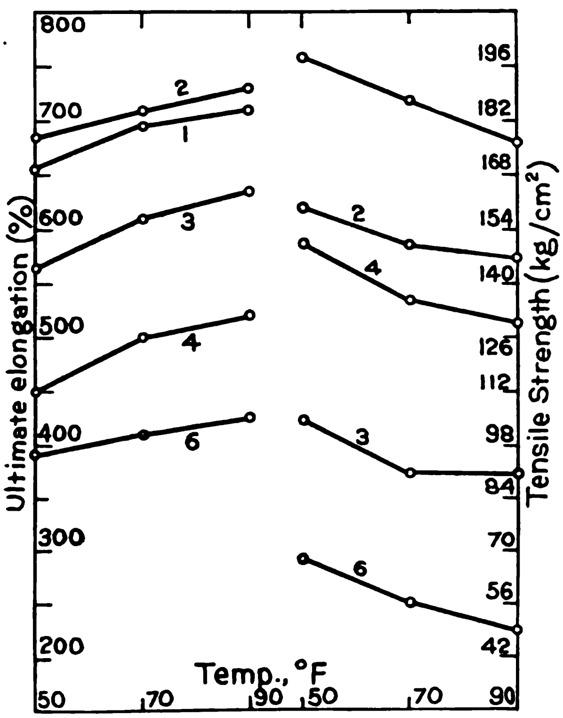


FIG. 20.—Influence of temperature on the tensile strength and ultimate elongation of five samples [32].

Stress-Strain Curve for Vulcanized Rubber

$$y = \frac{ax}{b + x} \qquad (1)$$

where y = strain; x = load referred to unstrained cross section; a = distance of asymptote from axis; b = intercept cut off by tangent at origin on the asymptote.

The curve is a rectangular hyperbola, with asymptotes parallel to the axes, with the equations

$$y = a, x = -b.$$

Making the asymptotes the axes

$$x'y' = -ab \text{ [82]}$$

$$\text{Stress} = Ee + e/B^{\frac{l}{k}} \qquad (2)$$

where e = elongation; l = original length; E = Young's modulus; B and k = constants [146].

Mechanical Hysteresis

TABLE 80

Extension and sub-permanent set in a succession of cycles of extension and retraction [24]. Pure gum rubber, sp. gr. 0.985, loaded at rate of 0.8 kg/cm² per 27 sec.

Cycle No.	1	2	3	4	5	6	7	8
Extension produced, %	516	568	590	604	617	627	636	643
Sub-permanent set, %	20	23	25	28	28	28	28	28

Extension, sub-permanent set, energy absorption, energy of hysteresis in succession of cycles of various amplitudes [80].

Extension in a series of cycles. Extension = $a + b$ log (No. of cycle) where a = extension in second cycle; b = increment of extension in subsequent cycles [140].

Influence of amount of extension on amount of hysteresis. In general, the shorter the cycle, the smaller the energy of hysteresis (*cf.* Fig. 23).

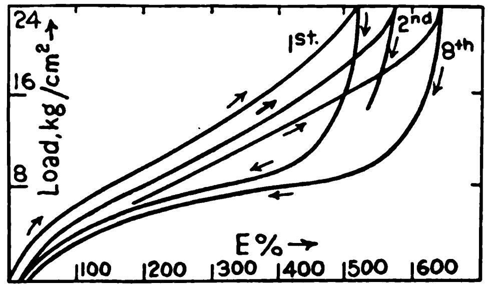


FIG. 21.—Load-strain curve for cycles Nos. 1 and 8 and part of cycle No. 2 (Table 80) [24].

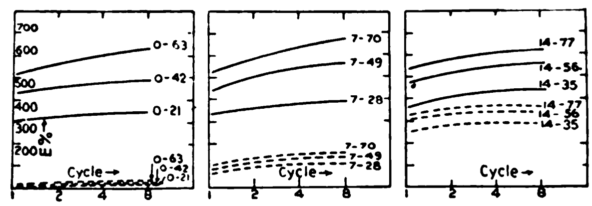


FIG. 22.—Relation between cycle number and max. (solid lines) and min. (dotted lines) extension for cycles between various loads. Stock: rubber (smoked sheet), 94 vols.; S, 3 vols.; MgO, 1 vol.; carbon black, 2 vols.; vulcanized 60 min at 149°. Load expressed in kg/cm² [80].

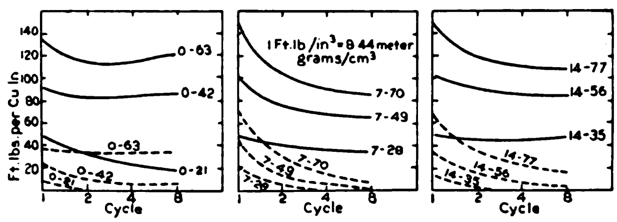


FIG. 23.—Relation between the cycle number and energy absorption (solid lines) and energy of hysteresis (dotted lines) for cycles between various loads. Load expressed in kg/cm² [80].

TABLE 81

Pure gum rubber subjected to a succession of cycles of different lengths, each cycle being repeated until the course of the load-strain curves was constant [24].

Cycle No.	Amplitude kg/cm²	Difference between elongation at same load during extension and retraction, %
1	0–4	61
2	0–8	167
3	0–12	286
4	0–16	533

Influence of rate of loading and unloading. The higher the rate of loading and of unloading, the smaller the extension and the greater the hysteresis [24].

Influence of state of cure and of the presence of a filler on energy absorption (Figs. 26 and 27) and energy of hysteresis (Figs. 28 and 29) in a succession of cycles of extension and retraction [80].

Stock A (by volume): rubber, 94; S, 3; MgO, 1; carbon black, 2.

Stock B (by volume): rubber, 63; S, 2; MgO, 1; carbon black, 2; whiting, 32.

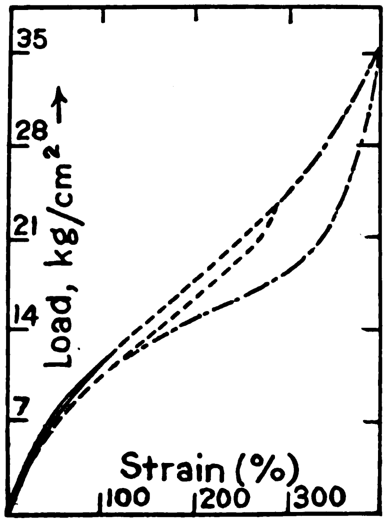


FIG. 24.—Pure gum rubber subjected to hysteresis cycles of different lengths (141).

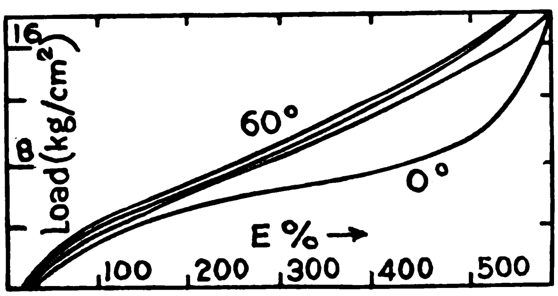


FIG. 25.—Influence of temperature on extension (24). Pure gum rubber, sp. gr. 0.985, loaded to 18.4 kg/cm² at 0° and 60°.

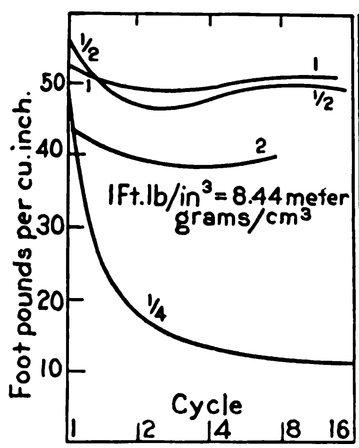


FIG. 26.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

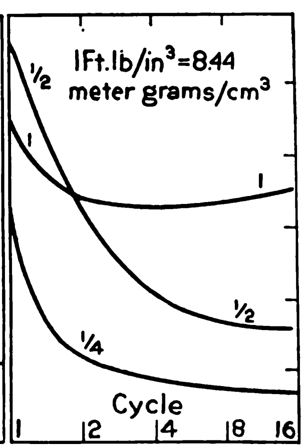


FIG. 27.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

Influence of compounding ingredients on Poisson's ratio for rubber (174). (P_v, P_t, P_w: Poisson's ratio from measurements of volume, thickness, width, respectively.)

1. $P_t = P_w = P_v$ at elongations up to 200: carbon black, ZnO.
2. P_t does not equal P_w; $P_v = 0.5$.

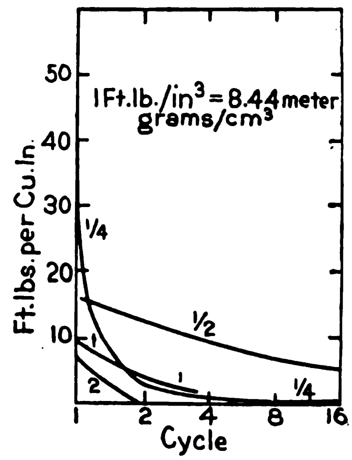


FIG. 28.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

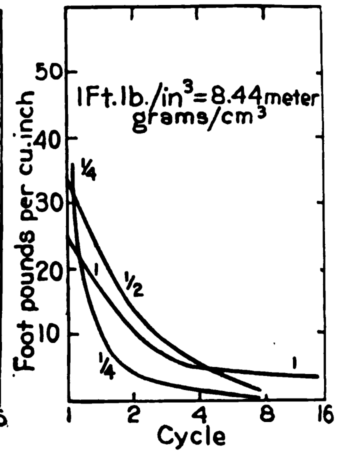


FIG. 29.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

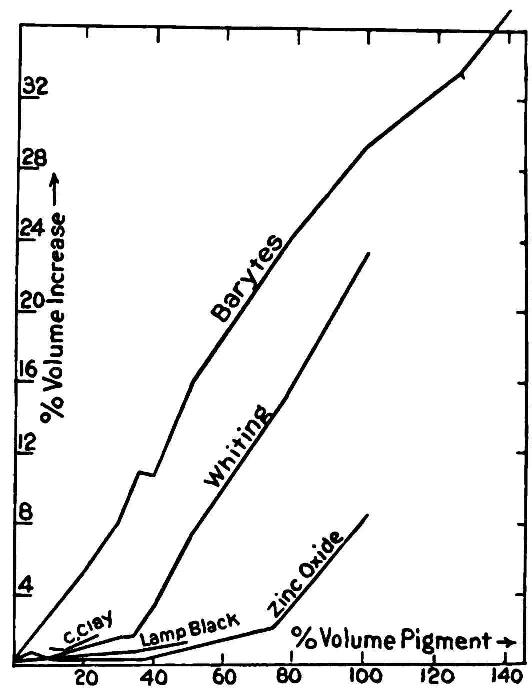


FIG. 30.—Increase in volume produced by straining to 100 % elongation stocks containing various volumes of barytes, china clay, lampblack, whiting and ZnO. Basal stock: rubber, 100; S, 5; litharge, 30 (139).

3. $P_w = P_t$; $P_v < 0.5$ at 300 %: barytes, lithopone.
4. P_w does not equal P_t; $P_v < 0.5$: tripoli at high elongations (*cf.* Fig. 32).

	At 25 % elongation		
	P_t	P_w	P_v
Magnesium carbonate	0.72	0.31	0.51
Clay	0.69	0.32	0.505
Tripoli	0.61	0.39	0.50

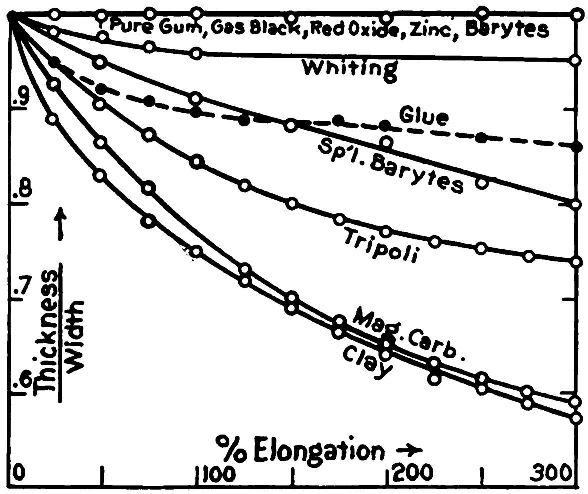


Fig. 31.—Effect of strain on the ratio thickness: width as influenced by various compounding ingredients (20 vols. per 100 vols. rubber) [174].

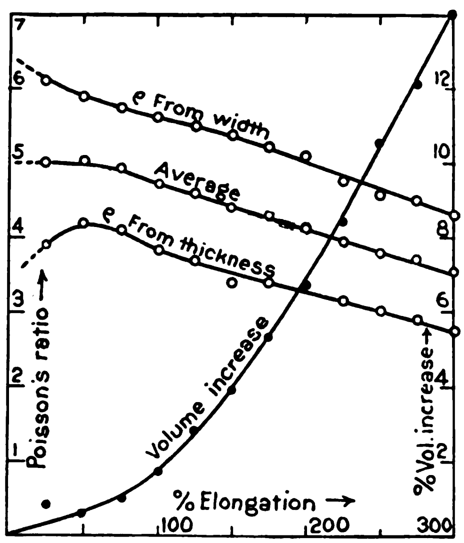


Fig. 32.—Effect of tripoli on Poisson's ratio and on increase in volume at various extensions [174]. Stock contains 20 vols. tripoli per 100 vols. rubber.

Load-Compression Relations. Pure Gum Rubber

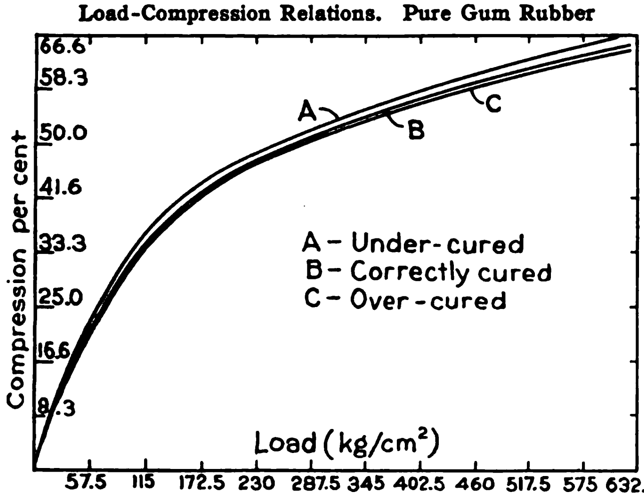


Fig. 33.—Load-compression curves for the stock: rubber, 100; S, 10; in various states of cure [17].

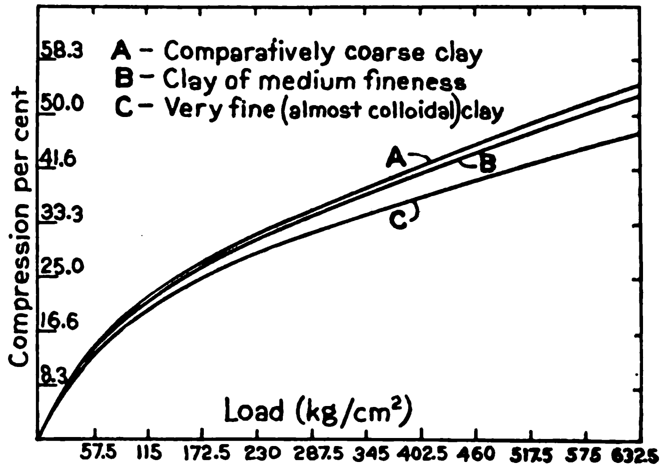


Fig. 34.—Load-compression curves for the stock: rubber, 100; china clay, 20; S, 10; ZnO, 5; diphenylguanidine, 1; using clay of different degrees of fineness [17].

Hardness

Definitions.—Plastometer number: the depression in hundredths mm produced by a steel sphere when the force against a surface of the rubber is increased from 85 to 1085 g, and then maintained for 60 sec [79].

Modulus of hardness: the force in dynes producing a depression of 1 cm³ [79].

See p. 270 for Figs. 35–39, giving illustrative values.

Resistance to Tearing

Table 82.—Influence of State of Cure on Resistance to Tear [231]

Stock: rubber, 92.5; S, 7.5; vulcanized at 145°

Time of cure, min.	30	45	60	75	90	105	120	135	150
Resistance to tear, kg/cm²	5.6	7.7	9.8	11.6	13.3	16.8	13.3	11.9	11.2

Compressibility

Compressibility.—92.95×10^{-6} of the original volume per kg/cm² [40]. Equal to that of bronze [2], *cf.* [105].

Volume Elasticity [107].—Soft, gray rubber (sp. gr., 1.289; T_B, 58; E_B, 890): 14 000 kg/cm². Red rubber (sp. gr., 1.407; T_B, *ca.* 58; E_B, 630): 8000 kg/cm². Gray rubber (sp. gr., 2.340; T_B, 58; E_B, 340): 66 000 kg/cm².

Thermal Properties

Expansion.—Coefficient of cubical expansion of:

(*a*) Sample of vulcanized rubber (sp. gr., 0.996), 2.25° above to 2.25° below its maximum density: 0.000526 [88].

(*b*) Sample of black vulcanized rubber (sp. gr., 0.90166 at 17.4°; S content, 2.5 to 3 %) at 0–60.7°: 0.000763 [105].

(*c*) Gray rubber: 0.000562 [105].

Specific Heat.—Above mentioned sample (*a*): 0.415 [88].

Conductivity.—Vulcanized rubber, crepe, smoked sheet, etc. (45–100°): 0.00032 cal/sec/cm³ [227].

Absorption

ABSORPTION OF ORGANIC VAPORS

Table 84.—Absorption (g/g Rubber) by Raw Rubber and a Rubber Stock (Rubber, 100; S, 12.5) Vulcanized to Various Degrees [93]

V. C.	0.0	1.2	2.0	3.5	4.4	6.4
Carbon tetrachloride	0.99	0.975	0.99	0.98	0.99	1.05
Benzene	0.98	0.895	0.87	0.86	0.86	0.85
Carbon disulfide		0.64	0.65	0.63	0.64	0.67

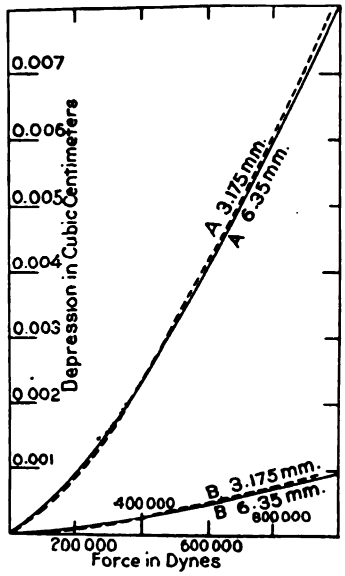


FIG. 35.—Force-volume depression curves for 2 samples of vulcanized rubber (steel balls 3.175 and 6.35 mm in diameter) (79).

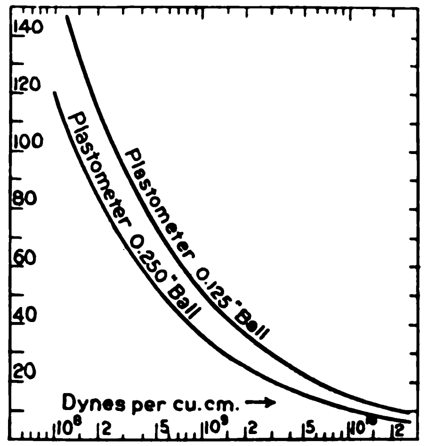


FIG. 36.—Relation between plastometer number and modulus of hardness (79).

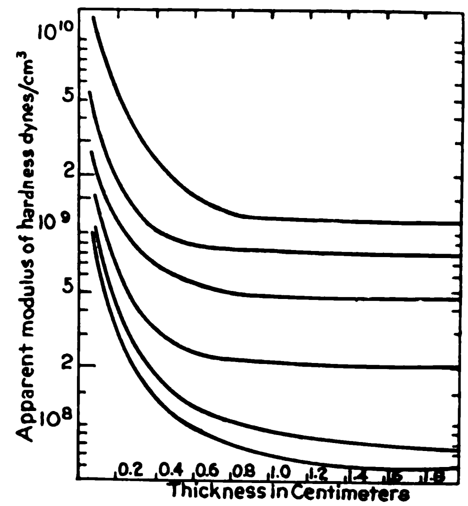


FIG. 38.—Influence of thickness of thin specimens on apparent hardness as determined by the plastometer (6 samples) (79).

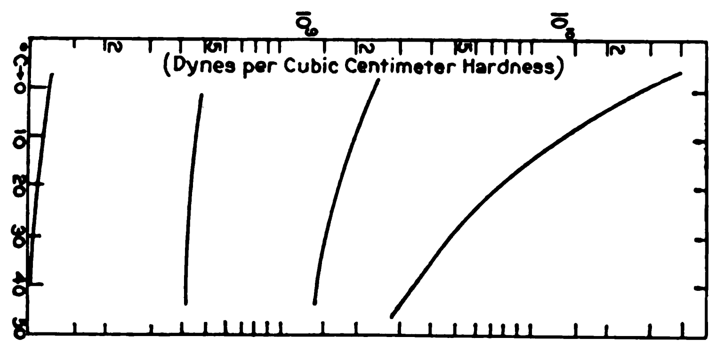


FIG. 37.—Change of modulus of hardness with temperature (4 samples) (79).

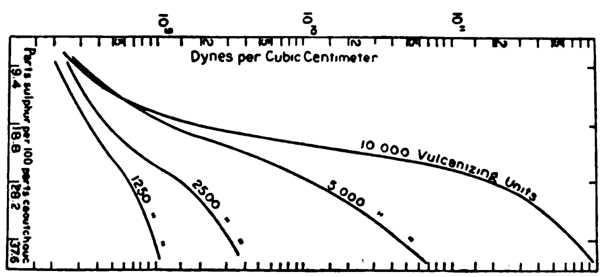


FIG. 39.—Modulus of hardness and degree of vulcanization (vulcanizing unit = (time of vulcanization at $t°$) $\times$ 1.1^{150-t} (79).

ABSORPTION OF WATER

TABLE 85.—ABSORPTION BY RAW RUBBER OF WATER FROM MOIST AIR (130), *cf.* (210)

Relative humidity, %		100	89	79	49	100	89	79	49
Type	Resin %	% absorption at 16°				% absorption at 30°			
Hevea sheet	3.32	1.85	0.88	0.31	0.23	2.88	0.76	0.44	0.24
Hevea crepe	3.43	2.80	0.89	0.39		4.54	1.06	0.37	
Castilloa	5.2	0.62	0.28			1.57	0.23	0.16	
Congo	16.7	6.02	2.12	0.9		15.8	2.58	1.26	0.42

Vulcanized rubber shows the same absorption from water vapor as from liquid water (22).

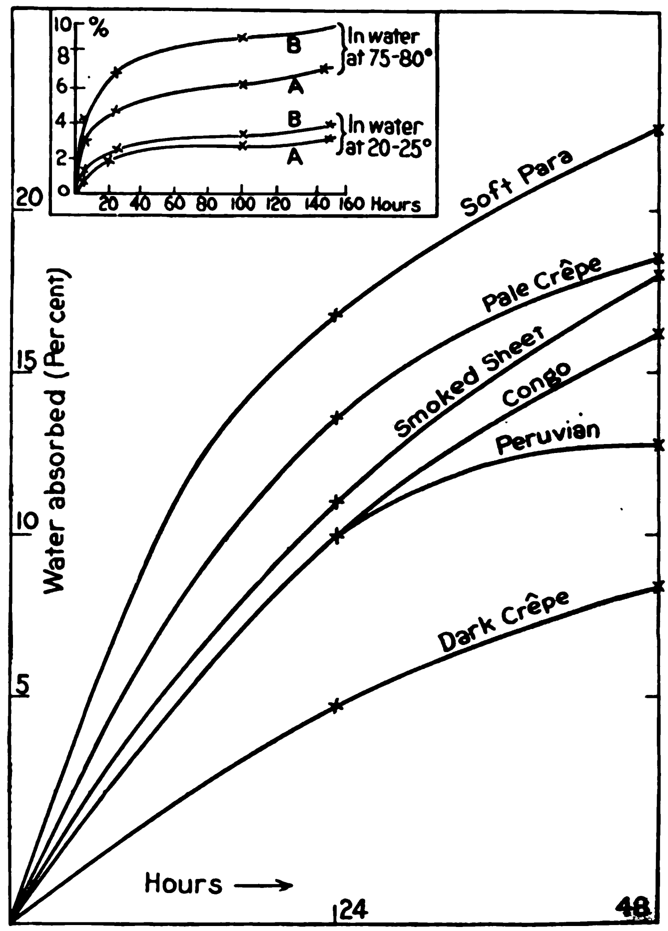


FIG. 40.—Various types of raw rubber in distilled water at 80–90° (94).

FIG. 41 (Insert).—Water absorption by cut sheet. Effect of temperature on (A) raw rubber, (B) cold vulcanised (94).

TABLE 86.—WATER ABSORPTION BY VARIOUS TYPES OF RUBBER

g/cm² surface of sheets 0.35 mm thick (22)

Type	t, °C	Immersion, hr	Absorption
Pale crepe	24	200	0.0356
	70	50	0.072
Smoked sheet	70	50	0.103
Fine Para	70	50	0.087
Latex sprayed	70	50	0.33
Vulcanized rubber*	24	50	0.0070–0.0097
	70	50	0.035–0.045
Hard rubber†	70	100	0.0137
Hard rubber‡	70	100	0.0110
Gutta-Percha	24	200	0.0122

* Stock: rubber, 24; ZnO, 18; whiting, 12; litharge, 3; S, 1.5; cured 60 min at 135°. Crepe, smoked sheet and fine Para used.
† Stock: rubber, 30; S, 17.5; *p*-nitrosodimethylaniline, 0.3; cured 120 min at 148°.
‡ Stock: rubber, 60; S, 35; cured 240 min at 148°.

TABLE 87.—ABSORPTION BY SAMPLES IMMERSED 18 WEEKS AT 15–25° (117)

Type	Medium	% absorption
Para rubber	Distilled water	31.77
Para rubber	Sea water	2.80
Gutta-Percha*	Distilled water	1.13–1.44†

* 4 samples; resin content: 20.3–46.3 %.
† Calculated on the gutta.

TABLE 88.—INFLUENCE OF DEGREE OF VULCANIZATION ON WATER ABSORPTION (94), *cf.* (22)

Stock: crepe, 100; S, 7; MgO, 5

Time of cure at 143°, min	15	30	60	120
Combined S, %	0.62	1.17	2.37	4.12
	% water absorbed			
Immersed 6 hr at 70–80°	4.45	3.6	2.8	2.3
Immersed 24 hr at 70–80°	5.32	4.74	3.9	2.9
After 48 hr more at 20°	13.2	10.5	7.8	5.9

Temperature coefficient for absorption of water by vulcanized rubber: 1.32–1.44 fold for each 10° rise in temperature (22).

Influence of pressure: water absorption is unaffected by increase of pressure from 1 to 5 atmospheres (22).

Imbibition of Liquids

TABLE 89.—IMBIBITION BY RAW RUBBER

cm³ liquid by 1 cm³ fine Para in 10 days at room temperature (151)

Carbon tetrachloride	12.05	Benzene	9.05
Chloroform	11.30	Xylene	8.89
Carbon disulfide	10.07	Ethyl ether	4.82
Toluene	9.52	Methyl alcohol	0.13

g liquid by 1 g fine Para under pressure of 1.12 kg/cm² (124)

Carbon tetrachloride	11.06	Benzene	4.41
Chloroform	9.31	Cymene	4.38
sym.-Dichloroethylene	7.35	Cumene	4.13
Thiophene	5.32	Ethylene chloride	2.71
Toluene	4.65	Ether	2.40

TABLE 90.—IMBIBITION BY VULCANIZED RUBBER

cm³ liquid by 1 cm³ rubber (sp. gr., 0.997; ash, 2; total S, 12.54; combined S, 1.28 %) in 24 hr at 17° (65)

Chloroform	9.64	Nitrobenzene	1.36
Carbon disulfide	8.11	Ethyl acetate	0.33
Toluene	7.40	Acetone	0.15
Xylene	6.35	Acetic acid	0.12
Benzene	5.86	Amyl acetate	0.085
Turpentine	5.52	Ethyl alcohol	0.025
Benzyl chloride	4.39	Methyl alcohol	0.02
Petroleum ether	4.38	Ethyl alcohol (96 %)	0.011
Kerosene	3.67	Water	0.005
Ethyl ether	3.43		

cm³ liquid by 1 cm³ "black rubber tubing," sp. gr., 1.06 (160)

Chloroform	7.37	Ethyl ether	3.09
Carbon disulfide	6.52	Ethyl acetate	0.71
Benzene	5.87	Acetone	0.21

g liquid by 1 g rubber, (stock: rubber, 90; S, 10; vulcanized 75 min at 148°) in 48 hr (214)

Benzene	3.63	Aniline	0.13
Toluene	3.84	Methylaniline	1.49
m-Xylene	3.01	Dimethylaniline	3.02
d-Pinene	2.57	*o*-Toluidine	0.69
Tetrahydronaphthalene	5.22	Diethylamine	6.24
n-Pentane	0.72	Piperidine	17.75
Carbon tetrachloride	8.50	Acetic acid	0.16
Chloroform	6.51	*n*-Butyric acid	1.57
Trichloroethylene	8.10	Dichloroacetic acid	14.20
Tetrachloroethane	8.19	Acetyl chloride	5.96
Tetrachloroethylene	6.47	Ethyl acetate	0.49
Pentachloroethane	8.02	Propyl acetate	1.27
Bromobenzene	6.17	*n*-Butyl acetate	1.43
Benzyl chloride	3.01	Isoamyl acetate	1.73
Phenyl mustard oil	3.21	Ethyl benzoate	2.26
Nitrobenzene	1.46	Cyclohexanol	0.58
Benzonitrile	2.20		

TABLE 91.—FACTORS INFLUENCING IMBIBITION

Degree of vulcanization: cm³ CCl_4 imbibed by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C. / Hours immersed	1.20	2.0	3.6	4.4	6.4
1	8.09	5.86	5.12	4.04	3.40
6	24.10	14.30	9.82	7.74	5.12
24	29.00	16.10	10.40	7.87	5.40

Temperature: cm³ C_6H_6 imbibed in 10 hr by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C. / t°C	1.2	2.0	3.6	4.4	6.4
40	8.73	6.30	5.16	4.33	3.30
50	9.00	6.55	5.37	4.60	3.60
80	10.70	7.56	5.85	5.20	4.00

Pressure: g C_6H_6 imbibed by 1 g raw fine Para (124)

kg/cm²	0.72	1.12	2.12	3.12	5.12
Imbibition	5.14	4.41	3.28	2.71	2.09

For similar data for toluene, cumene, cymene, ether, chloroform, carbon tetrachloride, ethylene chloride, *sym.*-tetrachloroethane, *sym.*-dichloroethylene and thiophene, *v.* (124).

TABLE 92.—VELOCITY OF IMBIBITION

Velocity of swelling (under a pressure of 1.12 kg/cm²)

$$k = \frac{1}{z} \log_e \frac{\omega_\infty}{\omega_\infty - \omega}$$

where k = a constant, z = time in minutes, ω_∞ = imbibition at equilibrium, ω = imbibition at time z, t = 17–18° (124).

Liquid	Benzene	Cumene	Chloroform	Thiophene
k	0.0019	0.0021	0.00057	0.00083

Solubility of Solids in Rubber

TABLE 93.—SULFUR (90)

In raw rubber: at 33°, 1.01; at 55°, 1.96 g/100 g raw rubber

In vulcanized rubber:

t, °C	Rubber: S ratio	hr cured at 141°	V. C.	Solubility g S/100 g stock
40	100:10	1	1.46	1.48
		2	2.98	1.45
		3	4.34	1.53
		4	6.54	1.61
		5	7.95	1.69
55	100:10	1	1.46	2.13
		2	2.98	2.24
		3	4.34	2.39
		4	6.54	2.56
55	100:30	3	5.47	2.36
		4	8.72	2.94
		5	13.92	3.00
75	100:30	3	5.47	3.22
		4	8.72	4.25
		5	13.92	5.42
		6	16.91	5.90

SELENIUM (228)

In raw rubber: <0.05 % at 80°C.

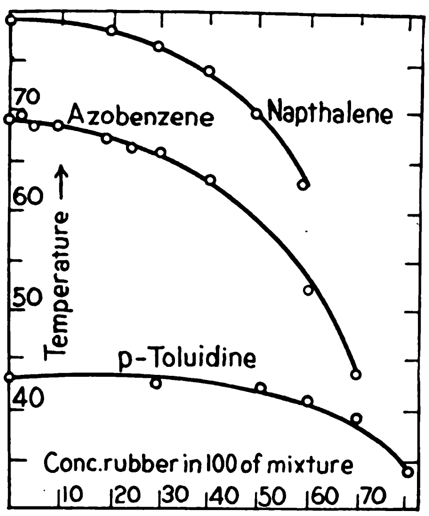


FIG. 42.—Solubility of naphthalene, azobenzene and p-toluidine in raw rubber (27).

Permeability to Gases and Vapors

Permeability is proportional to the partial pressure of the gas and to the thickness of the rubber (44, 59, 89, 229).

SPECIFIC PERMEABILITY

Unit.—cm³ gas/min/cm² area/cm thickness.

Hydrogen.—20.4 × 10⁻⁶ at 25° (vulcanized rubber on balloon fabric) (59). (5.520 + 0.876t) × 10⁻⁶, range 12.8 to 30.7° (sp. gr., 0.9455 at 18 to 20°) (89).

Carbon Dioxide.—(−5.084 + 2.928t) × 10⁻⁶, range 9 to 33° (sp. gr., 0.9455 at 18 to 20°) (89).

TABLE 94.—PERMEABILITY RELATIVE TO HYDROGEN AT SAME TEMPERATURE

In (59) samples are vulcanized rubber on balloon fabric. In (44) samples are vulcanized, probably by sulfur chloride

Gas	Relative permeability	t°, C	Lit.
Hydrogen	1		
Oxygen	0.445	25	(59)
	0.337	20	(44)
	0.500	25	(45)
	0.45		(72)
Nitrogen	0.160	25	(59)
	0.12	20	(45)
	0.18		(72)
Argon	0.23	25	(45)
	0.26		(125)
Helium	0.65	25	(59)
Air	0.230	25	(59)
	0.194	17	(44)
Carbon dioxide	2.91	25	(59)
	2.76	17	(44)
	2.8		(45)
	2.48		(89)
	2.47		(72)
Nitrous oxide	4.54	17	(44)
Ammonia	8	25	(59)
	11.4	17	(44)
Water vapor	55	25	(59)
Liquid water	105	25	(59)
Methyl chloride	18.5	25	(59)
Ethyl chloride	198	25	(59)

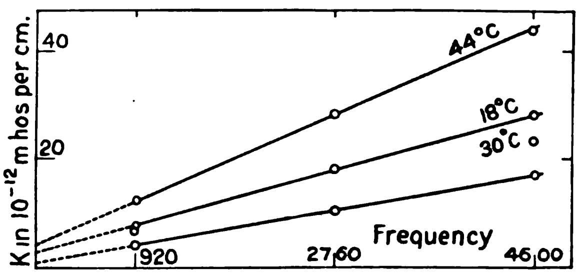


FIG. 43.—Variation of conductivity for raw india rubber with temperature and frequency (62).

Electrical Properties

RAW RUBBER, GUTTA-PERCHA AND BALATA

TABLE 95.—ELECTRICAL PROPERTIES OF RAW RUBBER (42)

Type	Age, mo	Number of samples	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10⁶ meg-ohm-cm)
Fine Para		13	2.43	0.14	35
Pale crepe		6	2.43	0.16	50
Pale crepe*		3	2.36	0.29	40
Smoked sheet	3	6	2.53	0.19	8
Smoked sheet	15	3	2.38	0.16	10
Smoked sheet*	12	3	2.35	0.29	60
Cameta		5	2.56	0.28	10
Guayule		2	2.69	0.51	60

* Thoroughly washed and dried.

TABLE 96.—ELECTRICAL PROPERTIES OF GUTTA-PERCHA AND BALATA (42)

	% composition*			H_2O, %	Dielectric constant at 1000 ~	Power factor % at 1000 ~	Resistivity (10^8 megohm-cm)
	Gutta	Resin	Mechanical impurities				
1. Gutta-Percha refined by acetone extraction	99.0		1.0	0	2.56	0.09	370
2. Gutta-Percha (Tjipetir plantation)	89.2	9.3	1.5	>0	2.60	1.1	65
3. No. 2 after drying	89.2	9.3	1.5	0	2.61	0.23	45
4. Gutta-Percha, refined.	79.9	19.3	0.8		2.78	0.35	60
5. Gutta-Percha, commercial	57.3	39.2	3.5	2.5	4.13	3.1	
6. No. 5 after drying	57.3	39.2	3.5	0	3.01	1.8	25
7. Resin from Gutta-Percha	0.0	100.0			3.27		25
8. Balata, commercial sheet	44.8	39.8	15.4		3.48	2.3	

* On dry weight.

TABLE 97.—INFLUENCE OF FREQUENCY ON ELECTRICAL PROPERTIES OF RAW RUBBER AND GUTTA-PERCHA (42)

	Dielectric constant				Power factor		Resistivity (10^8 megohm-cm)
	Alternating current		Direct current 0.6 sec charge, discharge		At 1000 ~, %	At 60 ~, %	
	1000 ~	60 ~	0.1 sec	1.0 sec			
Pale crepe	2.38	2.40	2.65	2.70	0.3	0.5	30
Gutta-Percha*	2.62	2.63	2.81	2.87	0.2	0.3	50
Gutta-Percha†	2.82	2.84	3.01	3.07	0.4	0.5	60

* Tjipetir. † Refined commercial.

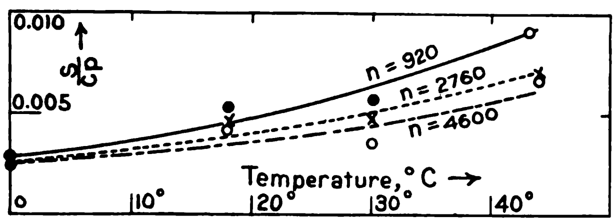


FIG. 44.—Variation of S/cp (power factor) with temperature and frequency for raw india rubber condenser (62).

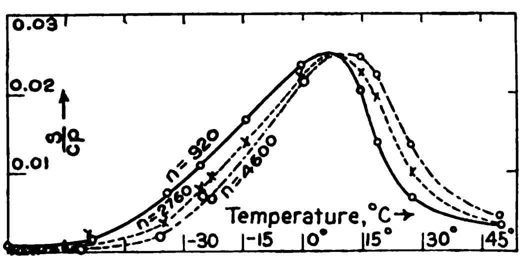


FIG. 45.—Variation of S/cp (power factor) with temperature and frequency for Gutta-Percha from −75 to 50°C (62).

TABLE 98.—INFLUENCE OF TEMPERATURE AND FREQUENCY ON ELECTRICAL PROPERTIES (62)

	Raw rubber			Gutta-Percha		
Frequency	920	2 760	4 600	920	2 760	4 600
Temperature, °C	18	18	18	15	15	15
Dielectric constant for alternating current	2.60	2.60	2.60	2.86	2.86	2.86
Temperature coefficient, per °C	−0.062	−0.062	−0.062	0.105	0.124	0.133
Temperature coefficient, range	0 to 43°	0 to 44°	0 to 44°	−14 to 50°	−14 to 50°	−14 to 50°
Resistivity, alternating current, megohm-cm	145 000	54 500	35 400	33 700	10 200	5 600
Power factor, %	0.005	0.005	0.004	0.020	0.023	0.025
Specific conductance for frequency n, micromicrohm-cm	$1.53 + 0.0058n$			$-16.9 + 0.04n$ (at 19°)		

TABLE 99.—INFLUENCE OF FREQUENCY AND TEMPERATURE ON CONDUCTANCE OF GUTTA-PERCHA (62)

Frequency	Conductance (κ) in bi-mhos (10^{12} mhos) per cm³										
920	t, °C	−75	−53	−34	−26	−14	0	15	19	27	50
	κ	1	2	10	15	22	33	30	20	10	4
2760	t, °C	−75	−54	−35	−25	−14	0	15	19	27	50
	κ	3	9	14	35	53	91	97	87	46	14
4600	t, °C		−56	−36	−25	−14	0	15	19	27	50
	κ		3	13	49	80	146	177	163	97	32

SOFT VULCANIZED RUBBER

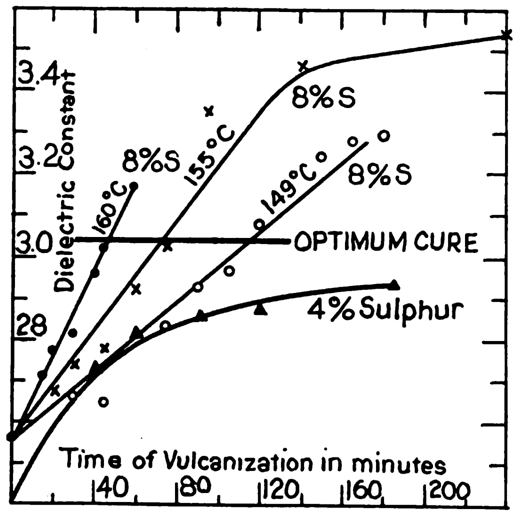


FIG. 46.—Dielectric constant at 1000 cycles; pure gum mixture (smoked sheet, 96; S, 4 and smoked sheet, 92; S, 8) vulcanized for various periods of time at various temperatures (42).

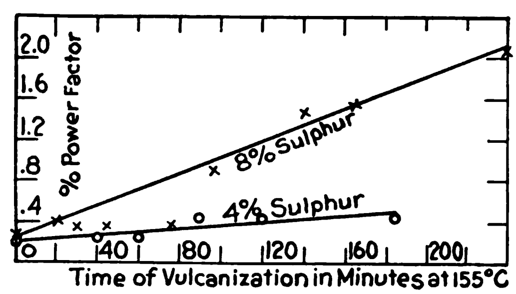


FIG. 47.—Power factor for samples described in Fig. 46 (42).

Resistivity: ranges from 10×10^8 to 150×10^8 megohm-cm irregularly (42)

TABLE 100 (42)

Composition				t, °C	Cure, min†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10^8 megohm-cm)
Rubber	Accel.*	ZnO	S					
Without free sulfur								
98	1	1	0	155	45	2.42	0.87	185
					90	2.40	0.81	195
92	3	5	0	126	15	2.49	0.42	20
					40	2.48	0.41	24
88	5	10	0	155	4	2.60	0.90	200
					12	2.59	0.80	220
85	5	10	0	126	20	2.66	0.47	20
					40	2.62	0.45	20
80	10	10	0	126	20	2.84	0.50	5

Table 100 (42).—(*Continued*)

Composition: Rubber	Accel.*	ZnO	S	t, °C	Cure, min*†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10^6 megohm-cm)
With free sulfur								
91.75	3	5	0.25	126	20	2.48	0.40	27
					35	2.45	0.26	45
92.5	2	5	0.5	126	10	2.51	0.23	150
					40	2.48	0.35	80
92.75	0.75	5	1.5	126	10	2.49	0.35	150
					25	2.49	0.34	210
90.75	0.25	5	4	126	15	2.60	0.23	90
					30	2.78	0.41	10

* Tetramethylthiuram disulfide.
† Extremes of range.

Table 101.—Influence of Frequency (42)

Composition	Dielectric constant: Alternating current, 1000 ~	Alternating current, 60 ~	Direct current 0.6 sec charge, discharge: 0.1 sec	1.0 sec	Power factor: At 1000 ~, %	At 60 ~, %	Resistivity (10^6 megohm-cm)
1. Rubber, 96; S, 4	2.89	2.90	3.25	3.32	0.35	1.2	20
2. Rubber, 90.75; S, 4; ZnO, 5; tetramethylthiuram disulfide, 0.25	2.67	2.67	2.86	2.94	0.20	0.2	80
3. (2) + ZnO, 75	9.76	10.3	11.9	13.1	1.9	4.8	0.5
4. (2) + carbon black, 20	6.12	8.61	10.3	12.4	7.5	10.5	0.4

Table 102.—Influence of Temperature and Frequency (62)

Frequency	920	2 760	4 600
Temperature, °C	17	17	17
Dielectric constant for alternating current	2.73	2.71	2.71
Temperature coefficient range (−14 to 83°)	−0.150	−0.130	−0.140
Resistivity, alternating current, megohm-cm	342 300	103 000	38 100
Power factor, %	0.2	0.2	0.4
Specific conductance for frequency n, micro-microhm-cm	$2.0 + 1180 \times 10^{-12}n^2$.		

Table 103.—Influence of Temperature and Frequency on the Conductance of Soft Vulcanized Rubber (62)

Frequency	Conductance (κ) in bi-mhos (10^{12} mhos) per cm³											
920	t, °C	−76	−63	−42	−32	−23	−14	0	17	41	60	83
	κ	2	4	32	50	26	19	7	3	8	12	16
2760	t, °C	−76	−63	−42	−33	−23	−14	0	17	42	61	83
	κ	4	8	53	141	102	76	31	10	18	29	41
4600	t, °C	−76	−63	−42	−32	−24	−14	0	17	44	60	84
	κ	3	9	62	220	205	158	57	26	26	43	57

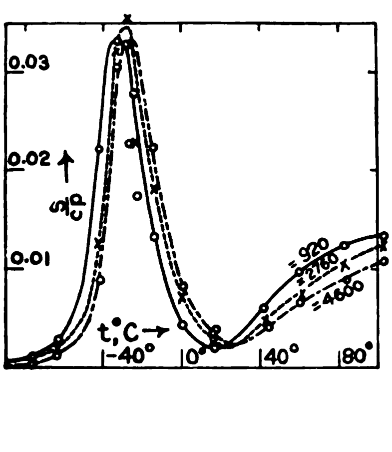


Fig. 48.—Variation of S/cp (power factor) with temperature and frequency for soft vulcanized rubber from − 90 to 100°C (62).

INFLUENCE OF COMPOUNDING INGREDIENTS

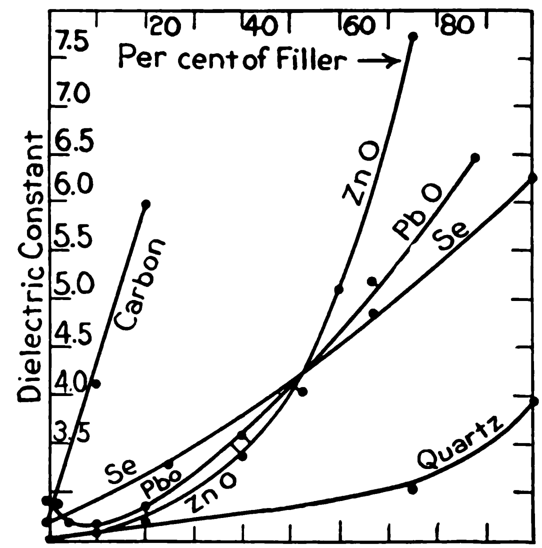


Fig. 49.—Influence of carbon black, ZnO, litharge, Se and quartz on dielectric strength (42).

In the case of ZnO, quartz, and Se, "% of filler" means the parts of filler by weight added to the following basal mixtures:

	Rubber	S	ZnO	Palm oil	Tetramethylthiuram disulfide
Zinc oxide	93.75	2		4	0.25
Quartz	92.75	2	1	4	0.25
Selenium	90.75	4	5		0.25

In the case of litharge "% filler" means the percentage present in the following series of mixtures:

Litharge	0	4	10	20	40	66	88
Rubber	96	88	82	74	52	22	9
Sulfur	4	4	4	6	8	11	1
Ozokerite		4	4				
Palm oil						1	2

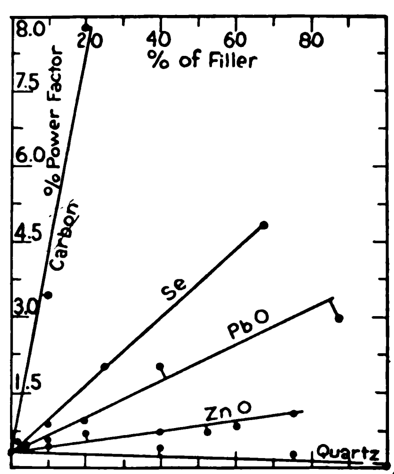


Fig. 50.—Influence of filler on the power factor at optimum cure (42); *cf.* note to Fig. 49.

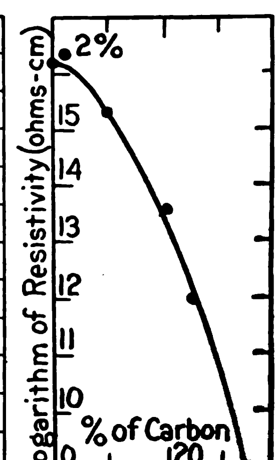


Fig. 51.—Influence of carbon black on the resistivity (42).

TABLE 104.—INFLUENCE OF BARYTES, "TITANOX," IRON OXIDE, TELLURIUM, CHINA CLAY AND ASBESTINE [42]

Stock No. 1: smoked sheet, 90.75; S, 5; ZnO, 4; tetramethylthiuram disulfide, 0.25%. Stock No. 2: smoked sheet, 90.75; S, 5; ZnO, 4; diphenylguanidine, 1%

Rubber mixture, %	Dielectric constant, 1000 ~	Power factor, %	Resistivity (10^8 megohm-cm)
No. 1	2.70	0.32	90
No. 1 + barytes, 45	3.37	1.1	20
No. 1 + titanox,* 50	3.77	1.1	13
No. 1 + iron oxide, 46	3.61	1.39	30
No. 1 + tellurium, 25	3.20	0.50	85
No. 2	2.62	0.75	190
No. 2 + china clay, 49	3.27	1.13	170
Rubber, 41; S, 2; ozokerite, 5.4; tetramethylthiuram disulfide, 0.1; asbestine, 50	4.24	2.1	14

* Approximate composition: titanium dioxide, 25; barium sulfate, 75 %.

INFLUENCE OF SOFTENERS

In a stock cured by the aid of tetramethylthiuram disulfide, the following softeners have little effect on the dielectric constant: ozokerite, 10; vaseline, 10; beeswax, 10; stearic acid, 10; palm oil, 5 parts.

The following increased the dielectric constant from 2.67 to the figures noted: *p*-coumarone resin, 10, to 2.80; mineral rubber, 33, to 2.88 [42].

HARD RUBBER

TABLE 105.—ELECTRIC STRENGTH [63, 63.5]

	Thickness, mm	Electric strength, kilovolt-mm	t, °C
1. Rubber with 35% S*	0.5	150	10–20
2. Medium quality	0.5	36	10–20
3. Medium quality	1.0	25	10–20
		18	60
	2.0	18	10–20
		11	60
4. Medium quality	1.0	45	10–20
		32	100
5. Switch handle quality	0.5	26	10–20

* Sp. gr., 1.201.

TABLE 106.—ELECTRICAL PROPERTIES OF VARIOUS GRADES OF HARD RUBBER [3]

	Admiralty sheet (U. S.)	G. P. O. sheet* (U. S.)	Sheet†	Rods and tubes‡	Radio panels and parts*
Specific gravity	1.22	1.20	1.19	1.18	1.46
Tensile strength, kg/cm²	635	530	440	480	395
Compressive strength, (kg/cm²) ‖ to laminations, 0.5 in. cube	338	282	245	265	220
Compressive strength (kg/cm²) ⊥ to laminations	359	300	249		237
Elongation, %	6.8	4.5	4.5	5.1	3.3
Electric strength (v/mm) alternating current	367	351	325	370	322
Resistivity (megohm-cm) × 10^6	26.6	30.2	32.9	628	100
Dielectric constant at radio frequencies					4.3
Water absorption (%) (24 hr at 50°)	0.03	0.04	0.05	0.04	0.08

* Mean of 3 samples.
† Mean of 4 samples.
‡ Mean of 5 samples.

TABLE 107 [42]

	Dielectric constant, 1000 ~	Power factor, %	Resistivity, megohm-cm
Rubber, 71.4; S, 28.6	3.50	0.4	110 × 10^8

TABLE 108.—INFLUENCE OF TEMPERATURE AND FREQUENCY [62]

Frequency	920	2 760	4 600
Dielectric constant for alternating current	3.17	3.15	3.14
Temperature coefficient range (0 to 84°)	0.360	0.310	0.290
Resistivity, alternating current, megohm-cm	148 500	38 500	23 100
Power factor, %	0.5	0.5	0.5
Specific conductance for frequency n, micro-microhm-cm	0 + 0.01n		

TABLE 109.—INFLUENCE OF HEAT AND IMMERSION ON THE ELECTRICAL PROPERTIES OF A MEDIUM GRADE OF HARD RUBBER [63.5]

	Electric strength, kv/mm at 10–20°			Volume resistivity, megohm-cm			Surface resistivity, megohm		
	Immersed	Sample No. 6	Sample No. 8	Immersed	Sample No. 6	Sample No. 8	Immersed	Sample No. 6	Sample No. 8
Normal		45	29		5 × 10^8	4 × 10^8		16 × 10^6	44 × 10^3
Water	24 hr	32	29	1 wk	5 × 10^8	5 × 10^8	1 wk	1.8 × 10^6	0.8 × 10^6
Brine	24 hr	37	35	1 wk	5 × 10^8	5 × 10^8	1 wk	1.7 × 10^6	27 × 10^3
H_2SO_4*				1 wk	5 × 10^3	5 × 10^6	1 wk	15 × 10^6	1.2 × 10^6
Oil	24 hr		30	1 wk	3.5 × 10^8 at 100°	5 × 10^8 at 50°	1 wk	26 × 10^6 at 100°	5 × 10^6 at 50°
Air				6 hr	1 × 10^8 at 100°	5 × 10^8 at 50°	6 hr	4 × 10^8 at 100°	4 × 10^8 at 50°

* Specific gravity, 1.21.

Table 110.—Influence of Compounding Ingredients ([120])
Stock: fine Para, 65; S, 35

Ingredient added	Sp. gr. of mixture	Electric strength, kv/mm
None	1.201	150
Talc	1.298	128
Soft palm pitch	1.185	118
Waste, soft grade	1.192	115
Hard palm pitch	1.224	108
Waste, hard grade	1.199	92
Caramba wax	1.171	78
Factice (vulcanized oil)	1.187	72
Zinc oxide	1.335	69

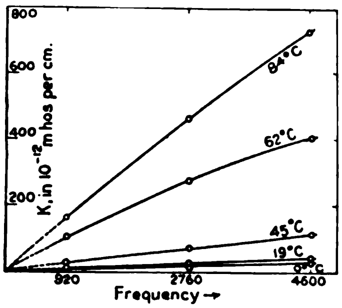


Fig. 52.—Variation of conductivity of ebonite with temperature and frequency ([82]).

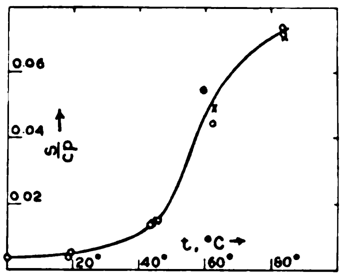


Fig. 53.—Variation of S/cp (power factor) for an ebonite condenser with temperature and frequency. Black dots denote 920, crosses 2760, and small circles 24 600 p. p. s. ([82]).

MILLING

Table 111.—Influence of Time of Milling on Plasticity ([78])

79 kg rubber (half sheet, half crepe) milled on a 214 cm fast mill. Extrusion time is the time in min required to extrude a length of 2 cm through the orifice of a Griffiths' plastometer at 85°.

Time, min	12.5	18	25	32.5	45	60
Extrusion time	2.77	2.05	1.72	1.47	1.23	0.97

Table 112.—Influence of Time and Temperature of Milling on Plasticity ([172])

k = plasticity determined by a Williams' plastometer

Milling conditions			Milling conditions		
Time, min	Temp., °C	k	Time, min	Temp., °C	k
13	100	4.7	30	40	2.0
25	100	3.7	60	40	1.6
55	100	3.0	120	40	1.3

Table 113.—Influence of Time of Milling on Viscosity of Rubber Solutions ([25, 130])

Time of milling, min		0	10	15
Viscosity number	Fine hard Para	72.1	24.8	15.2
	Latex crepe	49.6	20.4	16.4

Time of milling, min	2.5	5	10	15	20	30	40	50	60
Relative viscosity of 2% soln	1900	540	150	110	90	70	65	60	59

Table 114.—Time in Min Required to Produce a Given Degree of Plasticity

Influence of (*a*) distance between the rolls ("nip") and (*b*) the size of the batch of rubber on the time required to reduce rubber to a given degree of plasticity and the temperature acquired during milling in the case of a 214 cm mill, with a friction ratio of 1:1.5 and a surface speed of the front roll of 25.4 m per min ([78]).

	45.4 kg batch				79 kg batch			
Extrusion time, min	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	11	28.5	33	36.5	19	46.5	53	57.5
3.57	13	25	28	31	21.5	42.5	50	53.5
2.78	9	17.5	20.5	22.5	15.5	34.5	39.5	43
1.98	*ca.* 9	15.5	18	20	16	32.5	39	44.5
1.19	*ca.* 13	16.5	18.5	20	17	34	39	42
0.40		13.5	15.5	17	16.5	29		

	113 kg batch				147 kg batch			
Extrusion time, min	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	36				49			
3.57	31	60			41			
2.78	23	51	58	63	35.5	63		
1.98	30	51	57.5	62	35	59		
1.19	29	46.5	51	54	35.5	53	57.5	60

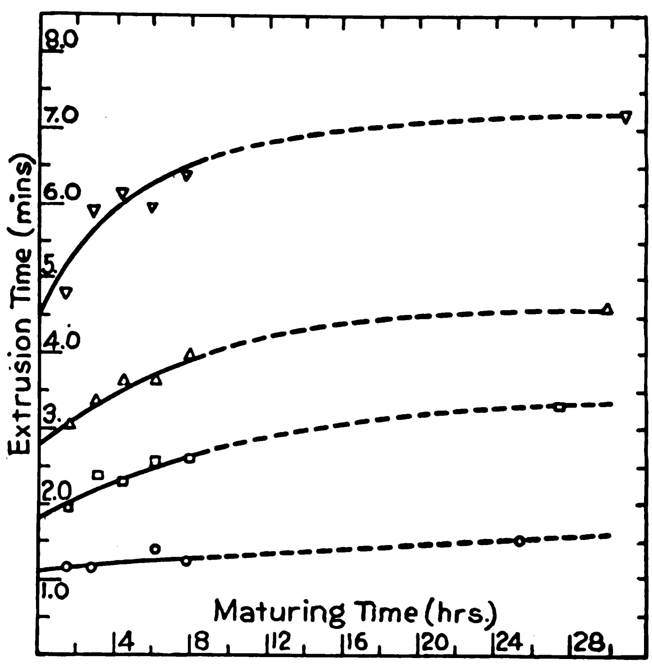


Fig. 54.

Recovery from Milling

Figure 54 shows the recovery from milling (expressed as maturing time/plasticity) of the same batch of typical pale crepe rubber milled to different degrees of plasticity and then allowed to remain at room temp. in the form of rolls 25 cm long × 7.5 cm diam. ([78]); the plasticity is expressed as the extrusion time in a Griffiths' plastometer (*cf.* Table 111).

Figure 55 shows the recovery of rubber (2 samples) from milling as shown by the viscosity of solutions (2 g in 97 cm^3 CS_2) after storage for various periods ([123]).

Figure 56 shows the influence of temperature of storage on recovery from milling (3 samples). "Hot" storage: 22.75 kg held at 42° in the form of a roll 25.5 cm long; "cold" storage: slices 6.3 cm thick cooled in water immediately after milling and held at room temp. ([78]).

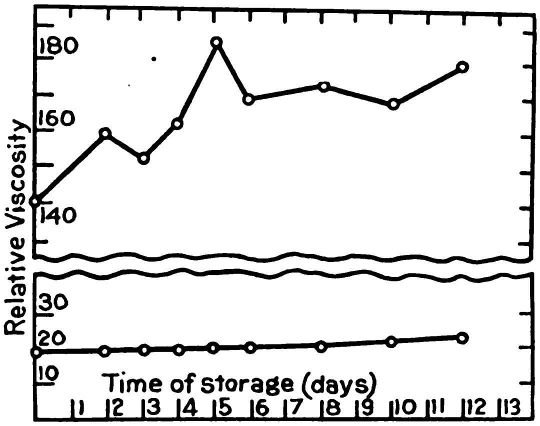


FIG. 55.

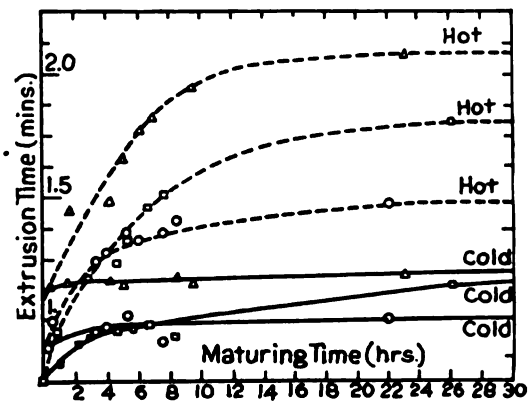


FIG. 56.

Calender Grain

Difference in tensile properties in the direction of calendering and at right angles to it (*cf.* Poisson's ratio).

Raw Rubber.—Sheet calendered on cloth: longitudinal direction, T_B, 7.1; E_B, 95. Transverse direction, T_B, 1.4; E_B, 533 ([127]).

TABLE 115

Vulcanized Rubber.—Stock calendered on cloth or on a cold calender roll ([224]).

X = rotation of the load-strain curve from the strain axis expressed as excess energy of resilience shown by test pieces cut along the calendar direction compared with pieces cut transversely to the calender direction, *i.e.*,

$$\left[\int_0^{x} \Delta T dE \Big/ \int_0^{x} T \text{ (with grain) } dE\right] \times 100,$$

the upper limit of integration being taken at 90 % of the mean E_B.

Z = displacement of the load-strain curve expressed as the extent to which the curve for test pieces in the calender direction has to be shifted along the strain axis to coincide with the curve for test pieces cut transversely to the calender direction.

a, vulcanized, wrapped, on mandrel; *b*, vulcanized in mold with no overflow.

Stock		1	2	3	4	5
a	*X*	9	5	21	27	18
	Z	10	12	30	45	40
b	*X*	12	5	15	23	11
	Z	30	8	25	50	35

Composition of stocks: (1) rubber, 97; S, 3 (by volumes); (2) rubber, 92; S, 4; ZnO, 4; (3) rubber, 90; antimony sulfide containing 40 % $CaSO_4$, 10; (4) rubber, 73; S, 3.5; litharge, 3; whiting, 18; gas black, 2.5; (5) rubber, 52; S, 8; litharge, 2; whiting, 35; gas black, 3.

Comparison of grain in calendered and in extruded rubber after vulcanization. Stock No. 3 (above) *a*: calendered, *X*, 21; *Z*, 30; extruded, *X*, 11; *Z*, 10 ([224]).

SOFTENERS

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) ([31])

Stock: rubber, 100; S, 5; ZnO, 1; diphenylguanidine, 0.25; vulcanized 90 min at 148°

Softener	%	Uncured stock		Cured stock		
		Plasticity*	Softness†	E_{60}	T_B	E_B
None		6.05	1.18	797	144	936
Mineral oil, sp. gr., 0.905; η, 951 190	0.125	5.32	1.31	784	152	921
	0.25	5.95	1.33	794	152	933
	0.5	5.75	1.38	800	150	948
	1	6.45	1.40	787	124	924
	2	6.75	1.42	797	121	912
	5	6.84	1.45	817	111	909
Vaseline	0.125	6.30	1.31	783	113	870
	0.25	6.35	1.31	801	145	900
	0.5	6.35	1.32	807	133	940
	1	6.27	1.36	817	131	941
	2	6.48	1.45	821	133	968
	5	6.60	1.48	826	116	935
Naphthalene	0.125	6.45	1.34	785	147	902
	0.25	6.45	1.36	794	135	917
	0.5	6.50	1.37	795	129	920
	1	6.69	1.38	800	127	922
	2	6.80	1.39	798	123	936
	5	6.85	1.39	814	107	920
Mineral rubber	0.125	6.20	1.31	819	144	960
	0.25	6.35	1.30	810	126	940
	0.5	6.35	1.30	806	110	910
	1	6.29	1.29	783	102	867
	2	6.55	1.31	772	98	894
	5	7.05	1.42	834	88	953
Pine tar	0.125	6.40	1.29	800	147	893
	0.25	6.47	1.33	807	128	925
	0.5	6.47	1.37	814	110	942
	1	6.55	1.37	831	110	947
	2	7.72	1.39	837	93	909
	5	7.83	1.42	902	93	972
Pine tar pitch	0.125	6.63	1.33	813	136	940
	0.25	6.63	1.35	810	135	937
	0.5	6.63	1.36	804	134	932
	1	6.25	1.39	815	114	922
	2	6.21	1.51	857	107	955
	5	6.21	1.64	933	84	1003
Rosin (colophony)	0.125	6.20	1.42	845	115	940
	0.25	5.90	1.42	824	104	926
	0.5	5.70	1.42	815	116	915
	1	6.20	1.50	852	114	954
	2	6.45	1.47	883	114	992
	5	7.10	1.56	930	82	948

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) [31].—(*Continued*)

Softener	%	Uncured stock		Cured stock		
		Plasticity*	Softness†	E_{60}	T_B	E_B
Rubber resin	0.125	5.80	1.47	825	119	936
	0.25	5.80	1.47	832	115	940
	0.5	6.12	1.48	859	108	957
	1	6.60	1.51	869	109	974
	2	6.65	1.58	916	84	975
	5	6.72	1.61	962	81	1020
Rosin oil	0.125	6.05	1.39	782	147	934
	0.25	6.11	1.40	775	146	920
	0.5	6.21	1.40	770	146	911
	1	6.30	1.39	775	136	902
	2	6.35	1.48	843	119	962
	5	6.43	1.67	896	92	968
Rape oil	0.125	6.22	1.30	747	147	887
	0.25	6.26	1.30	751	146	892
	0.5	6.35	1.30	758	144	907
	1	6.35	1.39	768	102	846
	2	6.55	1.47	808	125	926
	5	6.67	1.51	834	99	911
Linseed oil (raw)	0.125	5.12	1.30	785	132	910
	0.25	5.64	1.31	784	130	908
	0.5	6.15	1.30	780	139	905
	1	6.22	1.37	826	116	935
	2	6.55	1.42	789	115	898
	5	6.57	1.51	845	102	933
Olive oil	0.125	6.45	1.30	811	118	911
	0.25	6.70	1.33	828	113	922
	0.5	6.80	1.40	851	103	939
	1	7.10	1.44	853	123	972
	2	6.96	1.51	854	110	953
	5	6.60	1.60	868	104	962
Stearin	0.125	5.57	1.40	732	126	855
	0.25	5.57	1.40	739	131	865
	0.5	5.57	1.40	750	145	894
	1	5.60	1.43	770	144	930
	2	5.85	1.41	755	131	890
	5	7.02	1.40	790	130	930
Palm oil	0.125	6.25	1.42	798	142	939
	0.25	6.20	1.44	815	131	940
	0.5	6.23	1.44	824	128	949
	1	6.35	1.47	784	140	924
	2	6.66	1.51	815	107	906
	5	6.70	1.66	863	113	970
Oleic acid	0.125	6.35	1.38	865	119	963
	0.25	6.35	1.40	843	112	950
	0.5	6.40	1.44	846	108	943
	1	6.44	1.46	872	106	940
	2	6.95	1.56	827	98	1017
	5	8.12	1.82	1020	84	1080
Stearic acid	0.125	5.25	1.40	824	123	941
	0.25	5.35	1.44	827	126	950
	0.5	5.50	1.46	833	117	958
	1	6.30	1.53	858	126	989
	2	6.73	1.55	902	118	1030
	5	7.60	1.56	954	111	997

TABLE 116.—EFFECT OF SOFTENERS ON PROPERTIES OF CURED AND UNCURED STOCK (RING-SHAPED TEST PIECES) [31].—(*Continued*)

Softener	%	Uncured stock		Cured stock		
		Plasticity*	Softness†	E_{60}	T_B	E_B
Palmitic acid	0.125	6.45	1.40	783	129	910
	0.25	6.50	1.44	790	131	924
	0.5	6.55	1.48	800	137	930
	1	6.55	1.50	842	137	982
	2	6.60	1.58	919	104	1030
	5	6.70	1.63	954	105	1070
Ceresin wax	0.125	5.94	1.39	811	144	951
	0.25	6.07	1.40	802	144	940
	0.5	6.05	1.41	794	146	936
	1	6.27	1.46	815	142	952
	2	6.55	1.48	813	130	942
	5	7.08	1.44	820	118	933
Carnauba wax	0.125	5.17	1.46	864	117	977
	0.25	4.25	1.48	859	114	914
	0.5	4.44	1.51	830	114	977
	1	4.18	1.40	866	133	993
	2	3.80	1.48	855	114	977
	5	3.66	1.33	855	110	969

* Depression (mm) in 3 min in Williams' plastometer at 70° with a load of 5 kg on a disc 5 cm² in area and 1 cm thick.

† Depression (mm) with 3 mm steel ball under 0.5 kg load at room temperature.

TABLE 117.—INFLUENCE OF FATTY OILS ON TENSILE PROPERTIES OF PURE GUM VULCANIZATE [122]

Stock: rubber, 90; S, 10; vulcanized at 143.3°

Cottonseed oil		Time of cure, hr				
		1.5	2	2.5	3	3.5
T_s (kg)	without oil	3.7	5.25	6.5	8.5	10.9
	with 2% oil	3.15	4.2	6.1	7.6	9.7
T_B (kg)	without oil	19.1	25.1	25.8	30.0	33.8
	with 2% oil	9.6	18.8	24.2	20.4	18.0
E_B	without oil	936	877	820	769	726
	with 2% oil	857	896	831	730	619

Similar results with rape-seed oil, palm oil and mineral oil.

ACCELERATORS OF VULCANIZATION

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ARSENIC

TABLE 118.—EFFECT OF DIFFERENT AMOUNTS OF THE ACCELERATOR (EXPRESSED AS % OF THE TOTAL MIXTURE) UPON THE TIME OF OPTIMUM CURE FOR SLAB AND CREPE (52)

Stock: rubber, 90; S, 10; vulcanized at 140° (ring-shaped test pieces)

As_2O_3	Cure, min		As_2O_3	Cure, min		As_2O_3	Cure, min	
	Slab	Crepe		Slab	Crepe		Slab	Crepe
0	45	120	0	75	150	0	45	120
0.0002	40	105	0.4	37	60	0.0021	35	95
0.0096	40	95	0.8	35	77	0.1050	34	75
0.0192	45	95	3.2	40	105	0.315	40	115
			6.4	90	165	0.660	80	180

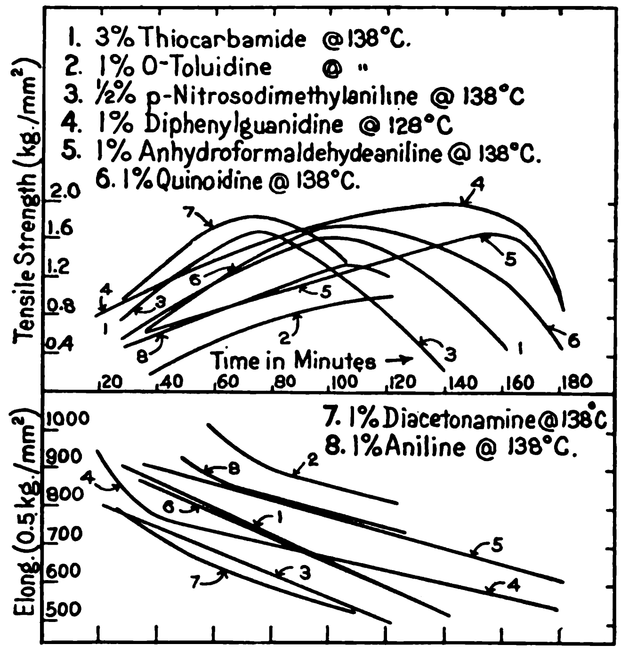


FIG. 57.—Various accelerators in the absence of ZnO. Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) (170).

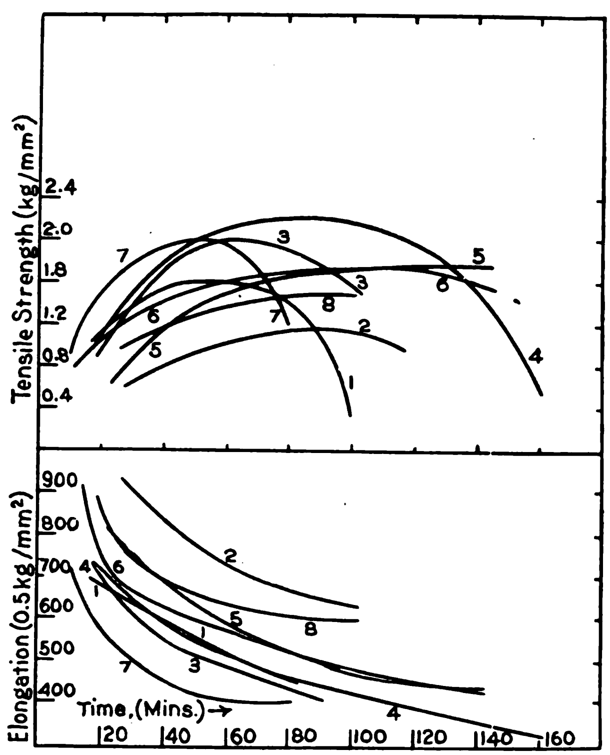


FIG. 58.—Various accelerators in the presence of ZnO. Basal stock: rubber, 90; S, 10; ZnO, 5. Tensile strength and stiffness (ring-shaped test pieces) (170). For key to numbers *see* Fig. 57.

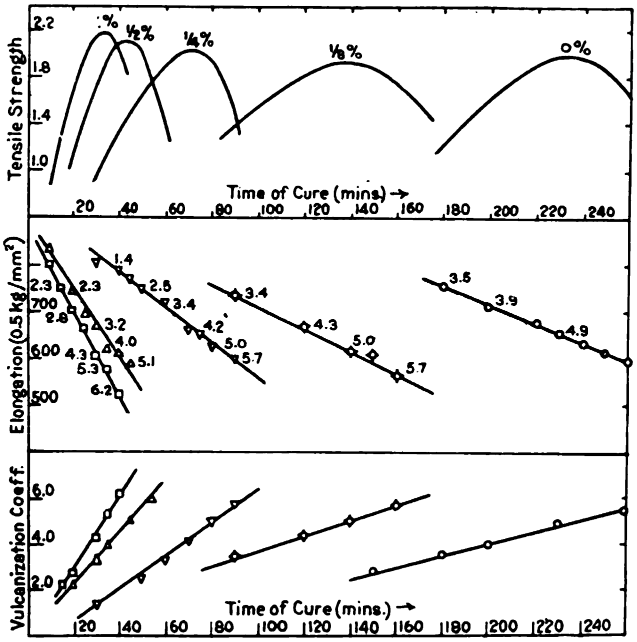


FIG. 59.—Influence of various proportions of aldehyde ammonia at 138° on rate of vulcanization, ultimate tensile strength, stiffness, vulcanization coefficient and flatness of curve. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) ([165]). Data are also given for vulcanization of the same mixture at 98°, 108°, 118°, and 148°. *Temperature coefficient* for these mixtures, *see* Table 70. ZnO has little or no effect on the activity of aldehyde ammonia ([165]).

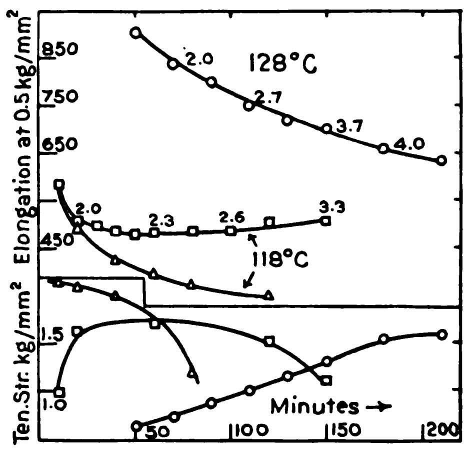


FIG. 61.—Piperidinium pentamethylenedithiocarbamate (0.25 part) with and without ZnO (ring-shaped test pieces) ([162]). ○—rubber, 90; S, 10. □—rubber, 90; S, 10; ZnO, 1. △—rubber, 90; S, 10; ZnO, 5. Vulcanization coefficients insert for curves ○ and □.

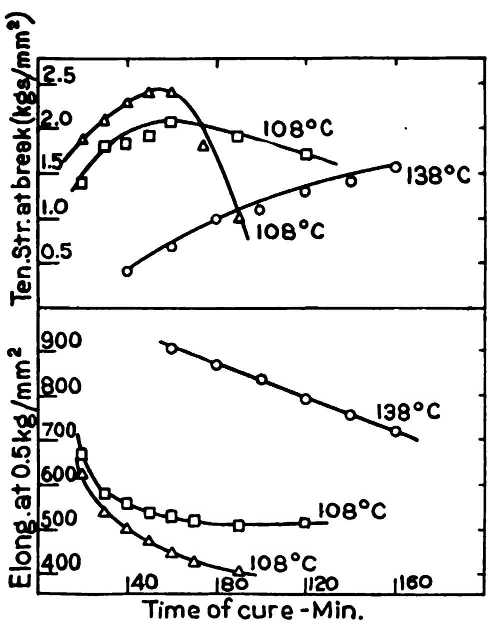


FIG. 60.—Zinc dimethyldithiocarbamate (0.25 part) when employed with and without ZnO (ring-shaped test pieces) ([166]). ○—rubber, 90; S, 10. □—rubber, 90; S, 10; ZnO, 1. △—rubber, 90; S, 10; ZnO, 5.

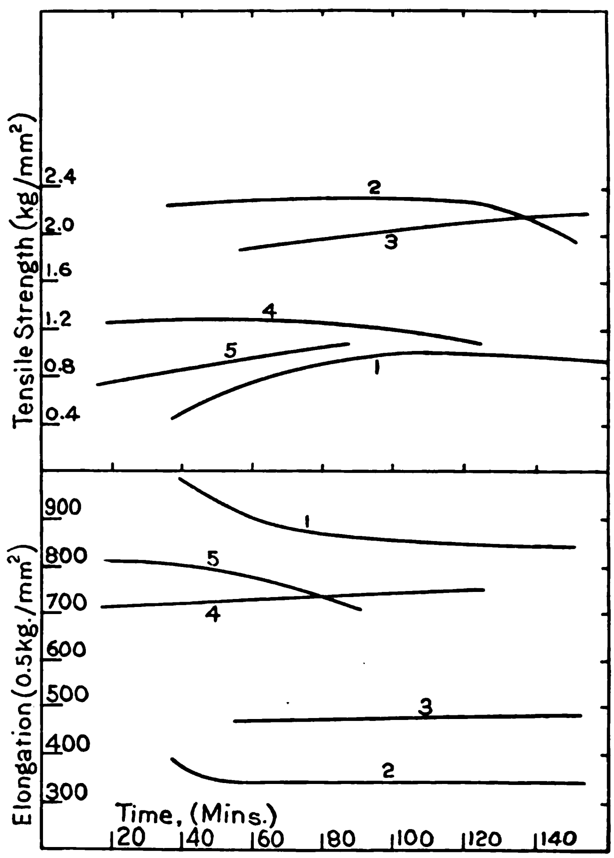


FIG. 62.—Dixanthogen (thiocarbethoxydisulfide)—influence of temperature and of proportion of ZnO. Tensile strength and stiffness (ring-shaped test pieces) ([170]). (1) 2.5 % dixanthogen, 1 % ZnO, 5 % S, 128°. (2) 2.5 % dixanthogen, 25 % ZnO, 5 % S, 98°. (3) 2.5 % dixanthogen, 25 % ZnO, 5 % S, 128°. Zinc methylxanthate—influence of temperature. (4–5). 3 % zinc methylxanthate, 1 % ZnO, 10 % S at 98° and 138° ([170]).

PIPERIDINIUM PENTAMETHYLENEDITHIOCARBAMATE

Table 119.—Effect of Concentration of Accelerator in a Low Sulfur Mixture [135]

Stock: rubber, 100; S, 2; ZnO, 2.5; vulcanized at 141° (ring-shaped test pieces)

Accelerator added in admixture with 3 parts of colloidal clay. These periods for vulcanization include those giving the maximum tensile strength.

Accelerator	5 min cure			7.5 min cure			10 min cure		
	E_{60}	T_B	E_B	E_{60}	T_B	E_B	E_{60}	T_B	E_B
0.25	773	128	1040	775	109	1008	743	98	934
0.50	600	172	870	585	144	817	534	115	800
0.75	612	176	902	583	186	870	579	217	894
1.0	516			510	256	830	523	182	794

Table 120.—Effect of Concentration of Accelerator in a High Sulfur Mixture [220]

Stock: rubber, 100; S, 7.5; ZnO, 5; vulcanized at 115° (straight test pieces)

Accelerator	20 min cure			30 min cure			40 min cure			60 min cure		
	T_6	T_B	E_B	T_6	T_B	E_B	T_6	T_B	E_B	T_6	T_B	E_B
0.25	57	215	805	133	307	740				137	302	745
0.33	66	234	815				134	324	760	164	335	730
0.50	159	325	715				247	336	650	280	298	615
0.66	230	321	660		267	590		215	515		194	370

Table 121.—Effect of Concentration of ZnO on the Activity of Piperidinium Pentamethylenedithiocarbamate [166]

Stock: rubber, 90; S, 10; accelerator, 0.25 (ring-shaped test pieces)

ZnO parts	Vulcanized at	Cure giving maximum tensile strength			
		Time, min	E_{50}	T_B	V. C.
1	118°	60	487	172	2.3
5	118°	10	587	214	
		20	504	210	1.6
20	118°	20	453	223	1.7
20	108°	30	454	219	

Table 122.—Comparison of the Effects of Piperidinium Pentamethylenedithiocarbamate (A) with Zinc Pentamethylenedithiocarbamate (B) and Zinc Phenylmethyldithiocarbamate (C) [220]

Stock: rubber, 100; S, 10; ZnO, 5; accelerator, 0.50 A or equivalent amounts B and C (straight test pieces)

Min	With accelerators; vulcanized at 115°									Control; vulcanized at 141°			
	A			B			C						
	T_6	T_B	E_B	T_6	T_B	E_B	T_6	T_B	E_B	Min	T_6	T_B	E_B
10	93	272	750	47	180	825	44	172	810	60	16	37	820
20	198	326	700	96	254	755	71	226	765	90	22	74	865
30	244	289	610							120	28	101	830
40	262	256	595	144	274	715	121	276	735	150	32	114	800
60		199	500	168	253	670	131	260	720	180	41	131	790
90		64	285	180	205	615	129	252	710	240		61	560
120							134	247	700	300		17	300

ETHYLIDINEANILINE AND ZINC MERCAPTOBENZOTHIAZOLE

Table 123 [123]

A = ethylidineaniline; B = zinc mercaptobenzothiazole; cure giving maximum tensile strength; vulcanized at 141.7° (straight test pieces).

Stock, parts			Accelerator		Cure, min	T_7	T_B
Rubber	S	ZnO	A	B			
100	3	5	0.5		40	*ca.* 95	*ca.* 200
100	4	5		0.6	30	*ca.* 90	*ca.* 200

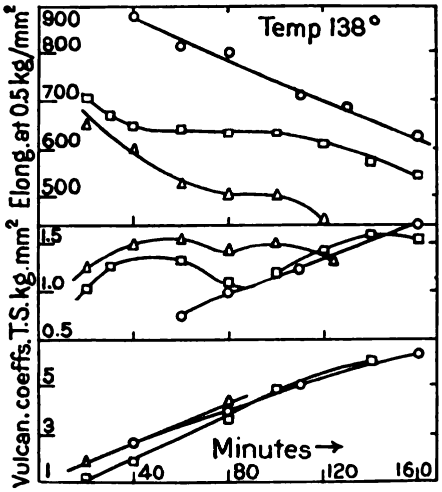


Fig. 63.—Furfuramide (ring-shaped test pieces) [163]. ○—rubber, 90; S, 10; furfuramide, 1. □—rubber, 90; S, 10; furfuramide, 1; ZnO, 1. △—rubber, 90; S, 10; furfuramide, 1; ZnO, 5.

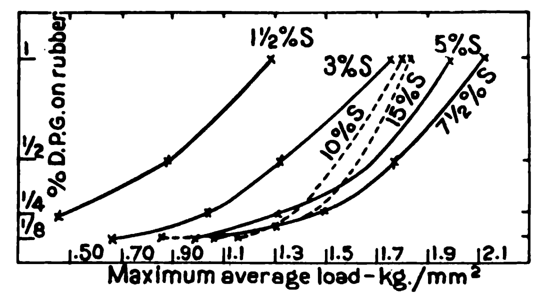


Fig. 64.—Diphenylguanidine with various proportions of S—maximum tensile strength attained. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) [4].

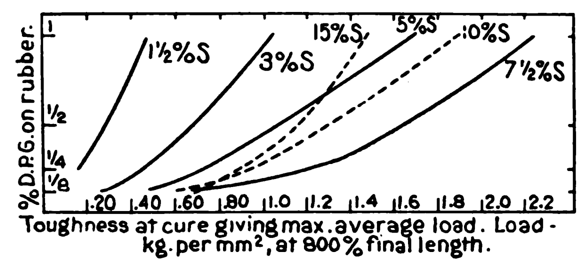


Fig. 65.—Diphenylguanidine with various proportions of S—maximum stiffness attained. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) [4].

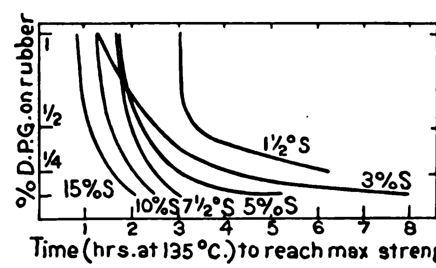


Fig. 66.—Diphenylguanidine with various proportions of S—rate of cure. Basal stock: rubber, 100; ZnO, 5; vulcanized at 135° (ring-shaped test pieces) [4].

DIPHENYLGUANIDINE

Table 124.—Effect of ZnO and "Light" $MgCO_3$ on the Action of Diphenylguanidine (4)

Cure showing maximum tensile strength; vulcanized at 135° (ring-shaped test pieces)

Accelerator parts	ZnO	$MgCO_3$	Cure, min	T_B	E_B	T_7
Stock: rubber, 100; S, 7.5						
1	5		90	213	687	131
1	30		105	190	677	138
1	5	15	75	210	594	216
0.125	5		180	106	823	36
0.125	30		270	97	761	44
0.125	5	15	195	160	762	81
Stock: rubber, 100; S, 3						
1	5		75	176	822	48
1	30		150	175	735	93
1	5		120	206	665	159
0.125	5	15	480	66	890	16
0.125	30		540	89	792	23
0.125	5	15	420	51	704	31

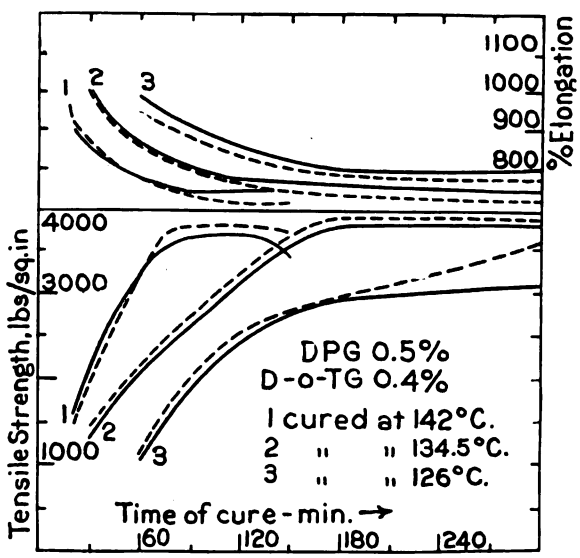


Fig. 67.—Diphenylguanidine (DPG) and Di-o-tolylguanidine (D-o-TG)—influence of temperature. Basal stock: rubber, 100; S, 4; ZnO, 3 (straight test pieces) (142).

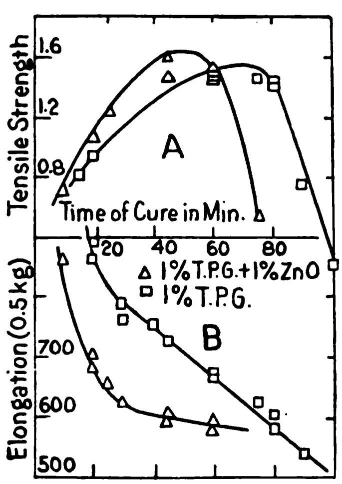


Fig. 70.—Triphenylguanidine—rate of cure as indicated by (A) tensile strength and (B) stiffness. Basal stock: rubber, 90; S, 10; vulcanized at 148° (ring-shaped test pieces) (167).

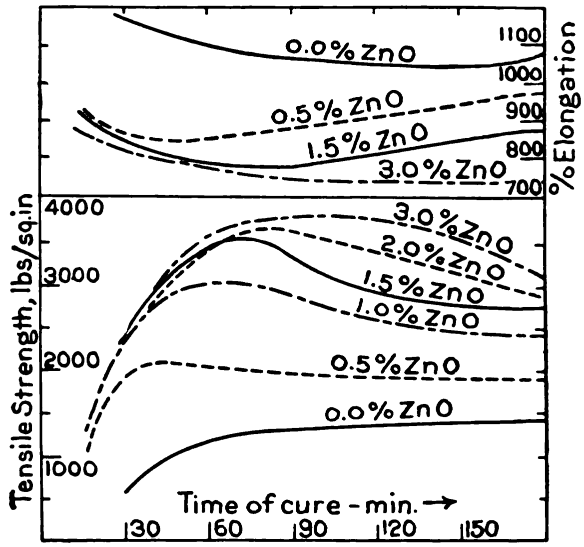


Fig. 68.—Di-o-tolylguanidine—influence of various proportions of ZnO on accelerating power. Basal stock: rubber, 100; S, 3; di-o-tolylguanidine, 0.5; vulcanized at 141° (straight test pieces) (142).

HEXAMETHYLENETETRAMINE

Table 125.—Effect of the Accelerator in the Presence of Great Quantities of ZnO (226)

Stock: rubber, 100; ZnO, 100; S, 7 (straight test pieces)

Cure, min	% hexamethylenetetramine 0		0.5		0.75		1.0		1.5	
	T_B	E_B	T_B	E_B	T_B	E_B	T_B	E_B	T_B	E_B
Vulcanized at 141.7°										
45			102	510	140	540				
60			140	550	163	520	152	520	147	480
90			148	490			188	480	158	420
120	82	680	146	480			197	470	198	410
150	87	550			183	460	140	340	119	300
180	88	500			205	460				
210	87	500								
Vulcanized at 147.8°										
30							119	540	152	500
45			154	520	154	510	180	500	186	450
60	82	500	160	500	172	520	176	500	180	440
90	93	500	188	490	188	480	163	420	103	270
120			159	470	159	410				
150	122	540								
180	116	530								
Vulcanized at 152.8°										
20									172	510
30							134	520	188	520
45			172	480	182	480	192	490	180	420
60	99	480	200	500	191	470	186	480	152	380
90	113	500	113	330	103	300	160	240		
120	122	540								
150	88	470								

LITHARGE

Table 126.—Influence of Small Quantities of Litharge (156)

Stock: rubber, 90; S, 10; vulcanized 60 min at 138° (ring-shaped test pieces)

% PbO	0	0.1	0.25	0.5	0.8
T_S	23.7	24.4	24.8	28.2	37.0
V. C.	1.26	1.25	1.27	1.37	1.75

MAGNESIUM OXIDE

TABLE 127.—INFLUENCE OF SMALL QUANTITIES OF MAGNESIUM OXIDE [156]

Stock: rubber, 90; S, 10; vulcanized 60 min at 138° (ring-shaped test pieces)

% MgO	0	0.1	0.25	0.4	0.75
T_s	15.2	39.0	75.5	112.0	132.0
V. C.	1.40	2.66	3.31	3.68	4.08

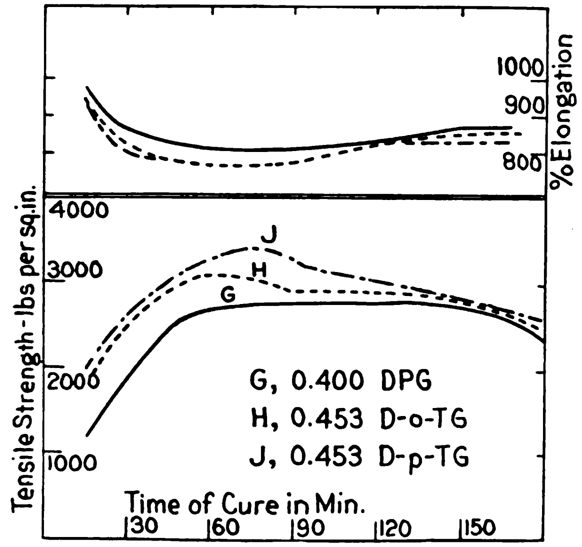


FIG. 69.—Comparison of the activity of equimolecular amounts of diphenyl-, di-o-tolyl- and di-p-tolylguanidine. Basal stock: rubber, 100; S, 4; ZnO, 1; vulcanized at 141° (straight test pieces) [142].

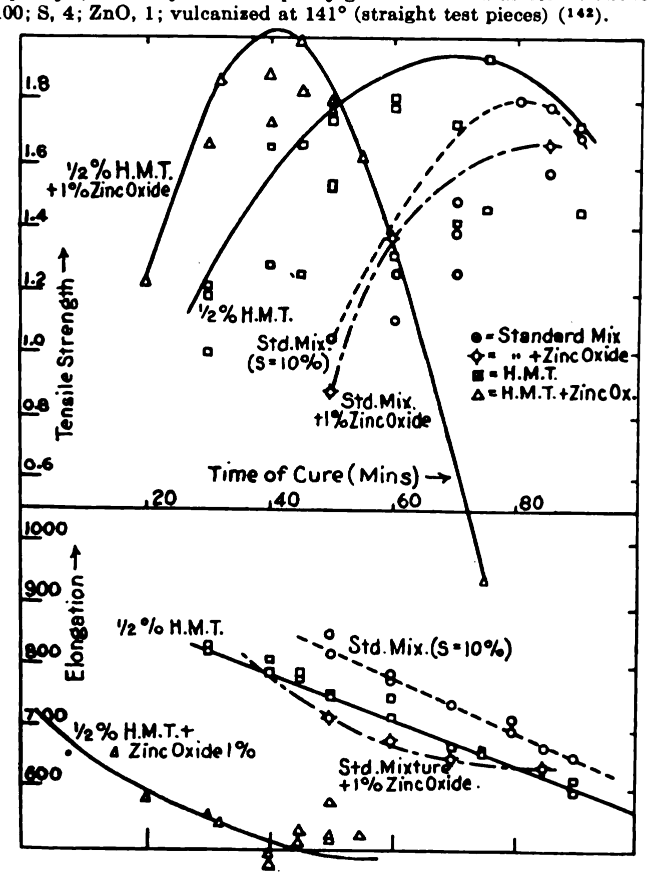


FIG. 71.—Hexamethylenetetramine (HMT) with and without zinc oxide. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) [168].

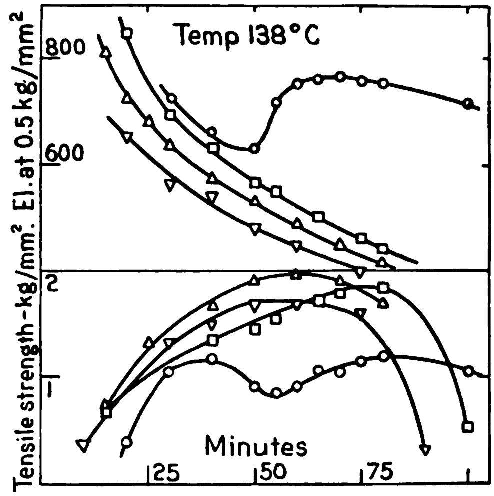


FIG. 72.—Hexamethylenetetramine (HMT) and zinc oxide. Tensile strength and stiffness (ring-shaped test pieces) [162]. O—rubber, 90; S, 10; ZnO, 0.5; HMT, 1. □—rubber, 90; S, 10; ZnO, 2; HMT, 1. △—rubber, 90; S, 10; ZnO, 5; HMT, 1. ▽—rubber, 90; S, 10; ZnO, 5; HMT, 2.5.

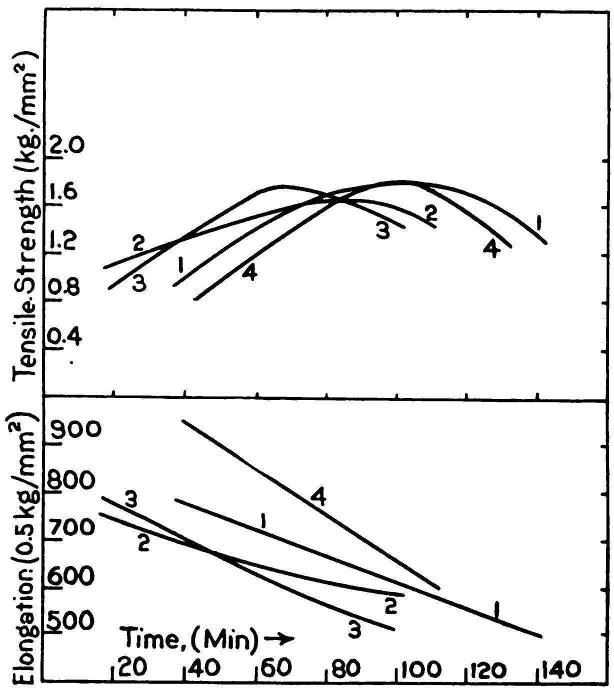


FIG. 73.—Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) [170]. (1) Sodium phenoxide (1 %) at 138°. (2) Zinc sulfate ammonia ($ZnSO_4.5NH_3$) (Sulzin) (1 %) at 138°. (3) Lime (5 %) at 138°. (4) Rubber, 90; S, 10 at 148°.

p-NITROSODIMETHYLANILINE

TABLE 128.—INFLUENCE OF ZnO AND MgO ON THE ACTION OF p-NITROSODIMETHYLANILINE [4]; *cf.* FIGS. 57, 58

Stock: rubber, 100; S, 10; accelerator, 0.5; ZnO or MgO, 5; vulcanized at 142° (ring-shaped test pieces)

ZnO				MgO			
Cure, min	T_s	T_B	E_B	Cure, min	T_s	T_B	E_B
20	31	133	875	15	24	90	886
30	35	103	804	25	41	166	890
50		24	465	35	44	135	834

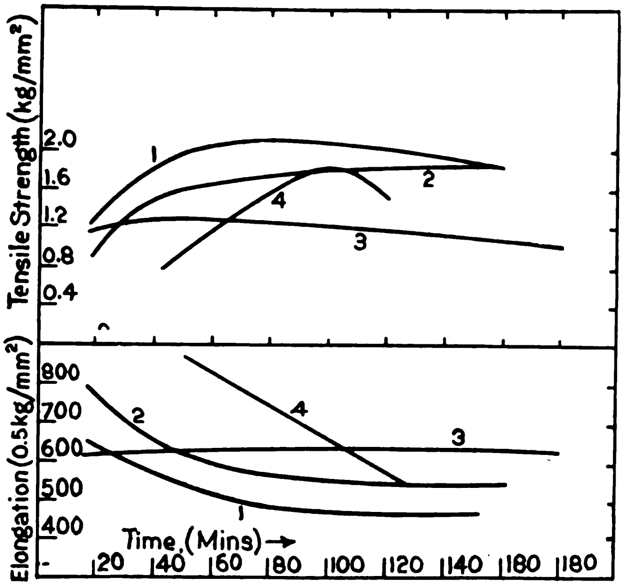


Fig. 74.—Basal stock: rubber, 90; S, 10. Tensile strength and stiffness (ring-shaped test pieces) ([170]). (1) Litharge (PbO) (20 %) at 128°. (2) PbO (10 %), ZnO (5 %) at 128°. (3) Mercuric oxide (HgO) (10 %) at 128°. (4) Rubber, 90; S, 10 at 148°.

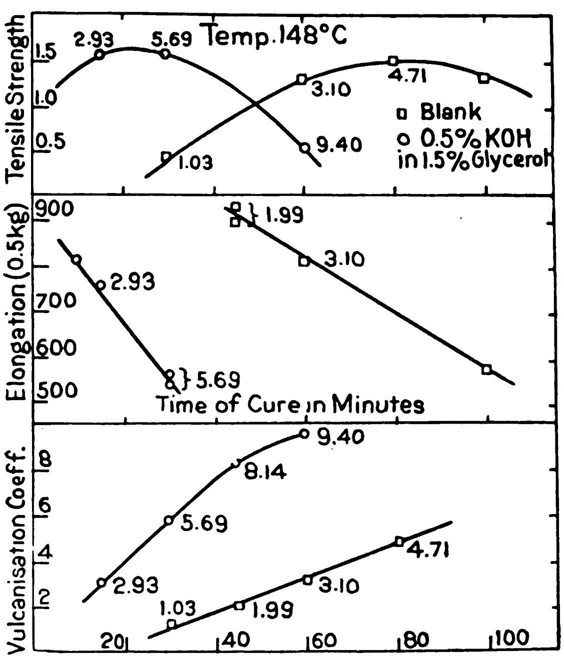


Fig. 77.—Potassium hydroxide. Tensile strength and stiffness (ring-shaped test pieces) (vulcanization coefficients inserted) ([167]). Basal stock: rubber, 90; S, 10. ZnO has little or no influence on the accelerating activity of KOH in rubber mixtures ([220]).

TETRAMETHYLTHIURAM DISULFIDE

Table 129.—Vulcanization with Tetramethylthiuram Disulfide; No Sulfur Added ([166])

Stock: rubber, 90; ZnO, 5; accelerator, 5 (ring-shaped test pieces)

t, °C	Cure, min	E_{50}	T_B
148	15	580	112
138	15	695	106

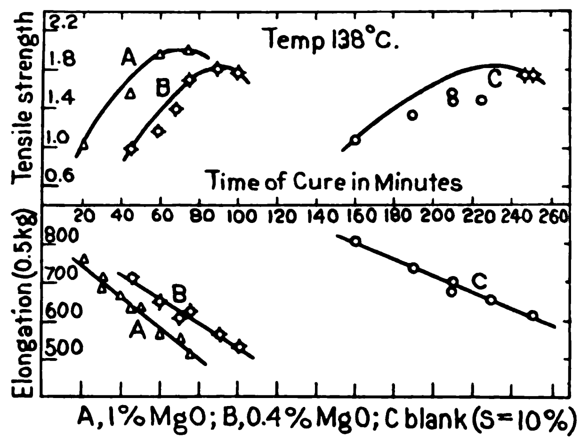


Fig. 75.—Magnesium oxide. Basal stock: rubber, 90; S, 10 (ring-shaped test pieces) ([167]).

ZINC XANTHATES

Table 130.—Effect of Zinc Ethylxanthate and ZnO on the Properties of the Vulcanizates at Optimum Cure ([169])

Ring-shaped test pieces

t, °C	Parts of: Accelerator	Parts of: ZnO	T_B	E_{50}
Stock: rubber, 90; S, 10				
108	1	0	71	852
108	0.5	1	85	761
108	0.5	5	120	665
Stock: rubber, 95; S, 5				
108	1	1	130	641
98	3	1	169	523
98	5	1	219	486
98	5	5	214	443
98	5	20	156	403
98*	10	1	177	441
98*	10	5	189	364
98*	10	20	163	292

* Badly over-vulcanized.

Table 131.—Effect of Zinc Ethylxanthate and S on the Properties of the Vulcanizates at Optimum Cure (Vulcanization Temperature, 108°) ([169])

Ring-shaped test pieces

Rubber	S	Parts/100 parts rubber + S: Accelerator	Parts/100 parts rubber + S: ZnO	E_{50}	T_B	V. C.
100	1.0	3	1	727	122	0.5
100	3.1	3	1	612	140	1.6
100	5.3	3	1	531	171	2.5
100	11.1	3	1	486	173	3.5
100	3.1	1	1	753	97	0.7
100	5.3	1	1	652	136	1.6

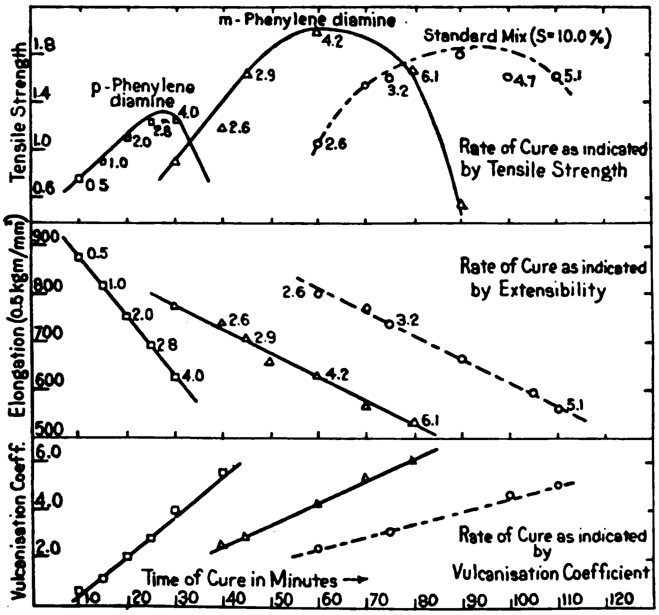


FIG. 76.—*m*- and *p*-Phenylenediamines (ring-shaped test pieces) ([165]). Basal stock: rubber, 90; S, 10.

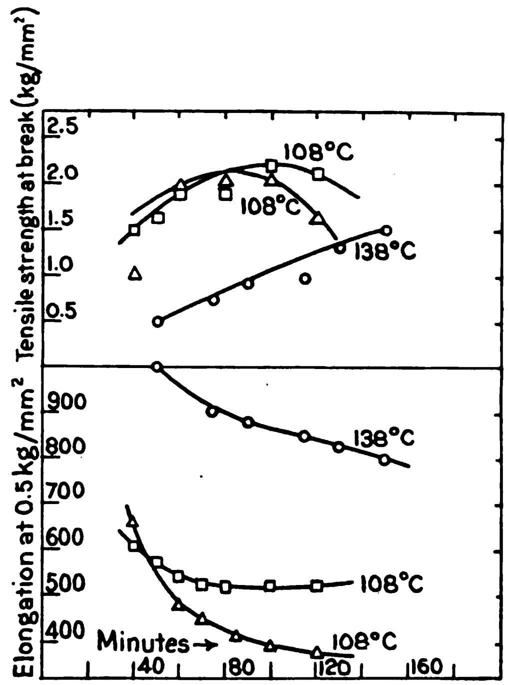


FIG. 79.—Tetramethylthiuram disulfide with and without ZnO. Tensile strength and stiffness (ring-shaped test pieces) ([166]). ○—rubber, 90; S, 10, tetramethylthiuram disulfide, 0.25. □—same + ZnO, 1. △—same + ZnO, 5.

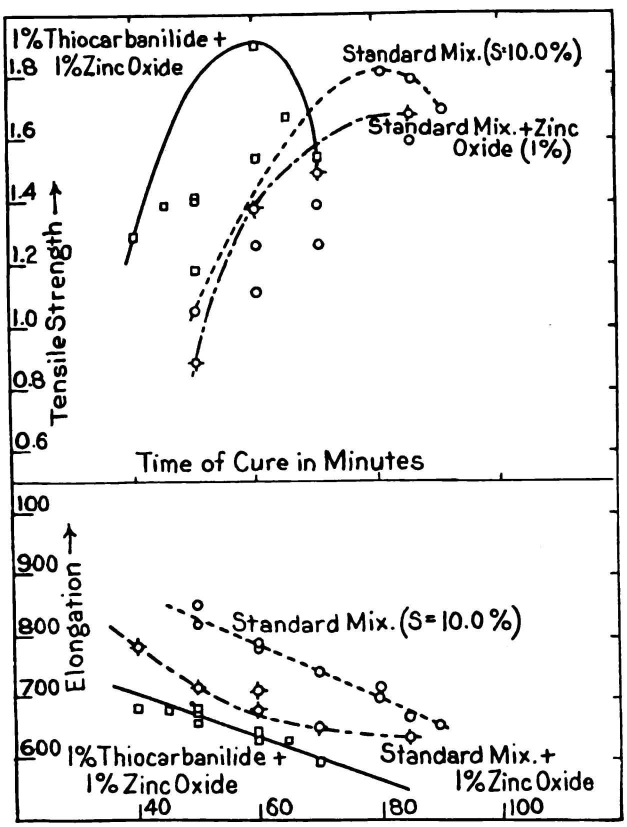


FIG. 78.—Thiocarbanilide (ring-shaped test pieces) ([165]). Basal stock: rubber, 90; S, 10. The "elongation" shown is the extension under a load of 0.5 kg/cm².

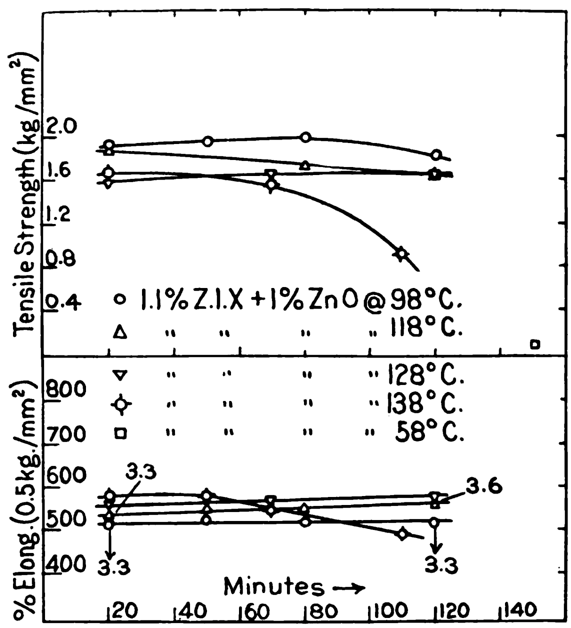


FIG. 80.—Zinc isopropylxanthate—influence of temperature and flat or static curing qualities. Tensile strength and stiffness. Basal stock: rubber, 90; S, 10. Figures inserted show vulcanization coefficients (ring-shaped test pieces) ([169]).

TABLE 132.—COMPARISON OF THE EFFECT OF VARIOUS ZINC XANTHATES AND INFLUENCE OF TEMPERATURE ON THEIR ACTIVITY (170)

Stock: rubber, 90; S, 10; ZnO, 1; data for optimum cures (ring-shaped test pieces)

Accelerator	Parts	Vulcanizing temperatures							
		138°		128°		118°		98°	
		E_{60}	T_B	E_{60}	T_B	E_{60}	T_B	E_{60}	T_B
Zinc isopropylxanthate	1.1	577	168	558	167	536	190	508	200
Zinc *n*-butylxanthate	1.2	631	154	600	168	580	175	543	199
Zinc *n*-propylxanthate	1.1	706	92	666	134	642	141	606	174
Zinc methylxanthate	1.0					960	59	932	65
	3.0	813	74	776	100	750	103	713	124

Zinc ethylxanthate, at 88°: E_{60} = 555; T_B = 205 (169). At 108° (1 part): E_{60} = 635; T_B = 185 (170).

COMPOUNDING INGREDIENTS

TABLE 133.—AVERAGE SIZE OF THE PARTICLES (74)

Ingredient	Microns	Ingredient	Microns
Carbon black	*ca.* 0.15	ZnO	
Lampblack	0.3–0.4	American process	0.4–0.6
Lithopone	0.3–0.4	French process	0.3–0.4
Sublimed white lead	*ca.* 0.65	Barytes, silica, asbestine, whiting	*ca.* 5–10
White lead	0.75–2		

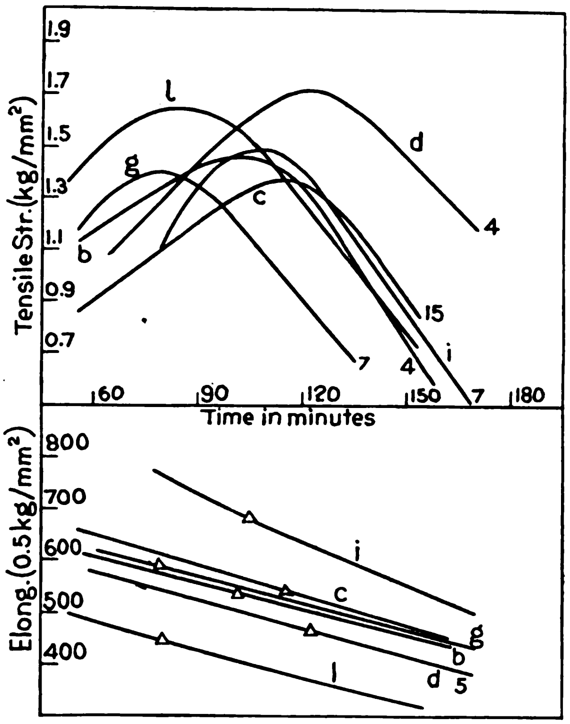


FIG. 81.

TABLE 134.—THERMAL CONDUCTIVITY (227)

For conductivity of rubber, *v.* p. 269

Compounding ingredient	Conductivity (cal/sec/cm³) (45–100°)	Compounding ingredient	Conductivity (cal/sec/cm³) (45–100°)
Antimony sulfide (15.6 % free S)	0.00021	$MgCO_3$	0.00103
Blanc fixe	0.00078	Red oxide	0.00132
Clay (Dixie)	0.00058	S	0.00012
Gas black	0.00067	Whiting	0.00084
Litharge	0.00051	ZnO	0.00166
Lithopone	0.00094	Cord fabric	0.00082*

* Approximately.

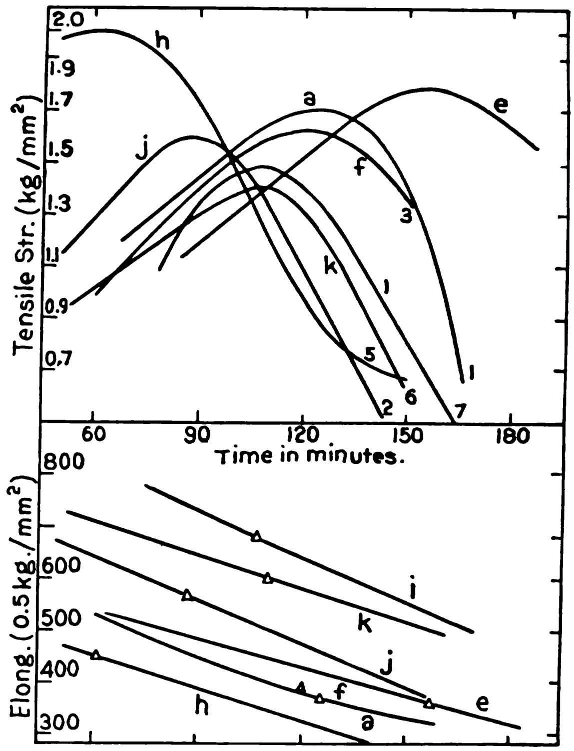


FIG. 82.

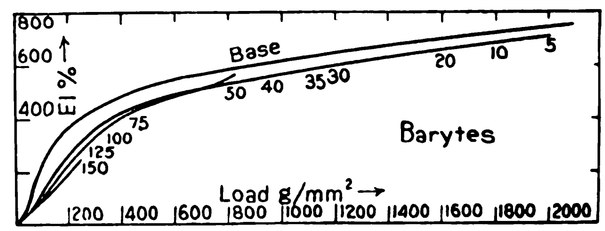


FIG. 83.

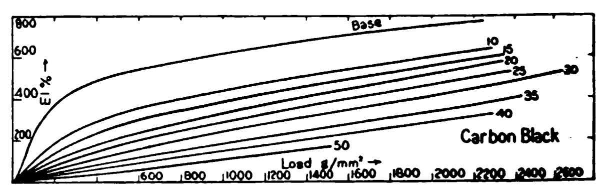


FIG. 84.

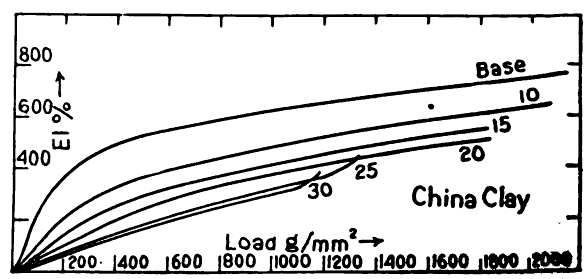


FIG. 85.

Figures 81, 82. Effect on the tensile strength, stiffness and rate of cure of an unaccelerated rubber-sulfur mixture (100:10) of 10 vols. of each of the following ingredients: (*a*) acetylene black; (*b*) pptd. barytes; (*c*) china clay; (*d*) colloidal clay; (*e*) gas black (carbon black); (*f*) lampblack; (*g*) lithopone; (*h*) $MgCO_3$; (*i*) mineral rubber (bitumen); (*j*) thermatomic carbon; (*k*) whiting; (*l*) ZnO (the figures in the upper set of the curves show the number of results of which each curve represents the mean. Ring-shaped test pieces used) (168).

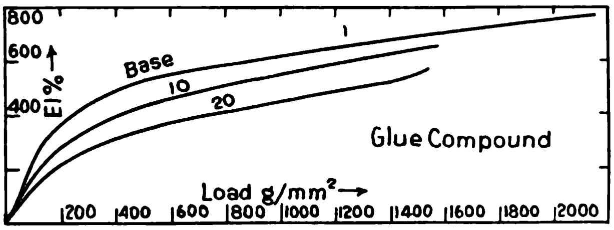


FIG. 86.

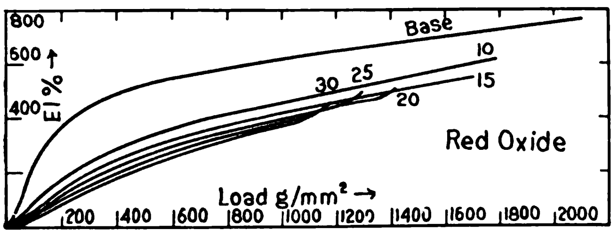


FIG. 87.

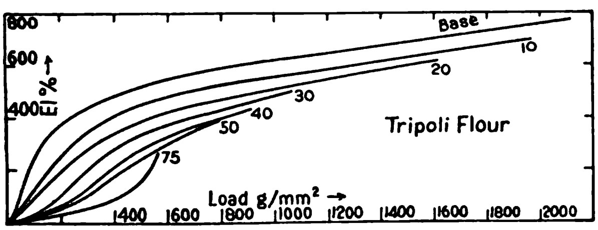


FIG. 88.

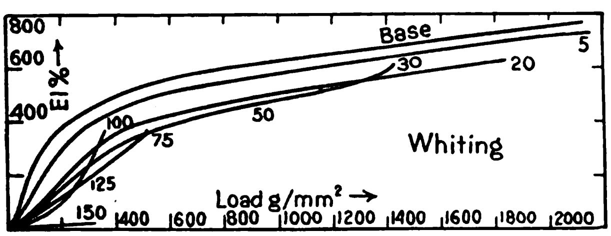


FIG. 89.

Figures 83–90. Effects on load-strain relations of various volumes of barytes (83), carbon black (84), china clay (85), glue (86), red oxide (87), tripoli flour (88), whiting (89), ZnO (90), added to the basal stock (rubber, 100; PbO, 30; S, 5. Stocks were vulcanized at 141° to approx. max. tensile strength) (223).

Figure 91. Effect on the load-strain relations of adding 5 vols. of barytes, carbon black, china clay, lithopone, titanium white, whiting or ZnO to the basal stock (rubber, 77.5; S, 5 vols.), vulcanized 175 min at 141° (ring-shaped test pieces) (104).

Figure 92. Influence on load-strain relations of various proportions of "light" $MgCO_3$ added to the basal stock (rubber, 100; PbO, 30; S, 5; vulcanized 45 min at 143°) (straight test pieces used) (75).

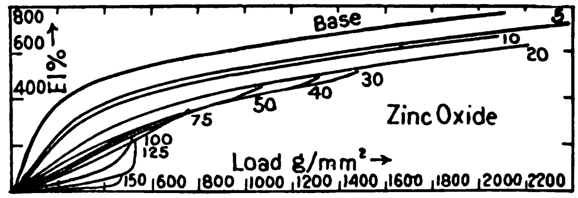


FIG. 90.

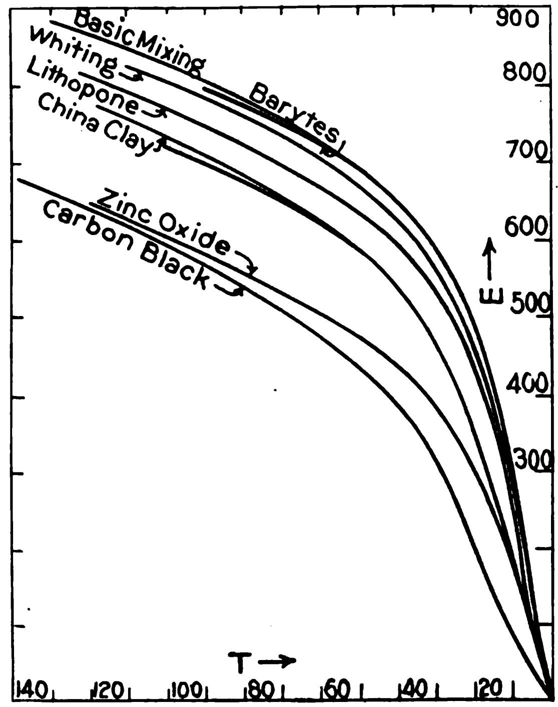


FIG. 91.

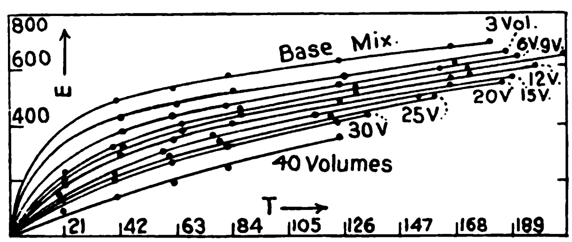


FIG. 92.

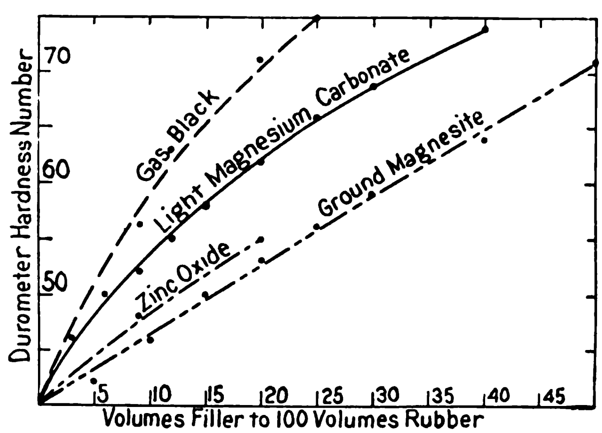


FIG. 93.

The influence of various proportions of carbon black, "light" $MgCO_3$, magnesite and ZnO added to the basal stock (rubber, 100; PbO, 30; S, 5; vulcanized 49 min at 143°) on the hardness of rubber is shown in Fig. 93; on the sub-permanent set in Fig. 94 (75).

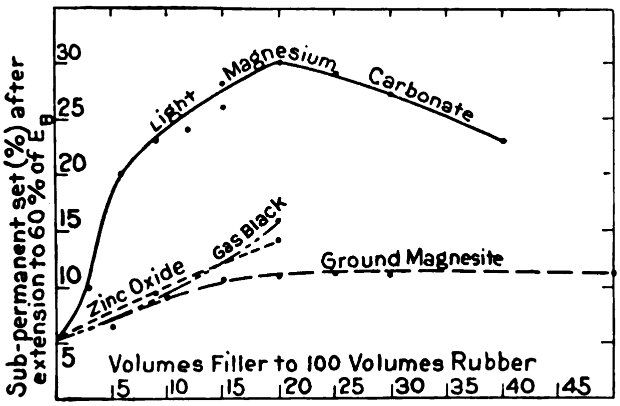


Fig. 94.

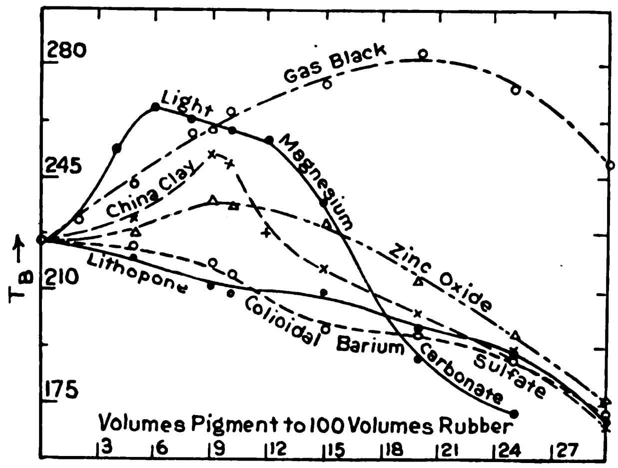


Fig. 95.

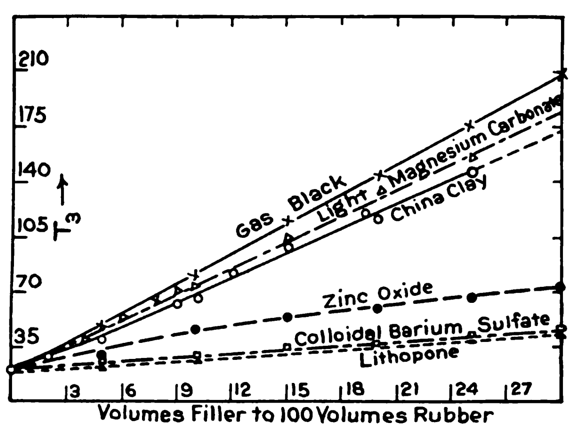


Fig. 96.

The effect of adding various proportions of $BaSO_4$ (colloidal), carbon black, china clay, $MgCO_3$ (light), lithopone, and ZnO to the basal stock (rubber, 100; ZnO, 5; S, 5; hexamethylenetetramine, 1; basal stock cured 80 min at 148°; other stocks given a slight undercure) upon the ultimate tensile strength is shown in Fig. 95; stiffness, Fig. 96; resilient energy, Fig. 97; resistance to abrasion, Fig. 98; and hardness, Fig. 99 (straight test pieces used). The resistance to abrasion is expressed as the percentage loss in weight of disks 5.625 cm diameter by 0.2 cm thick when rotated for 100 000 revolutions (10 hr) in loose granular carborundum (76).

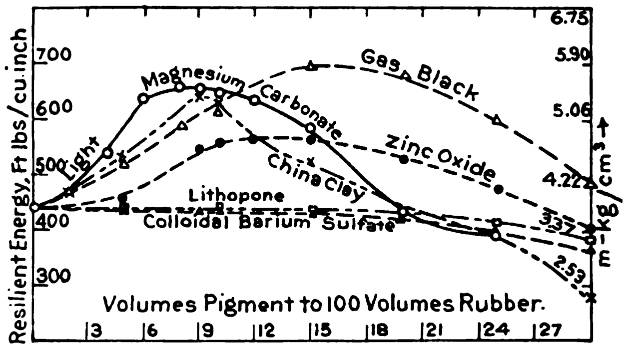


Fig. 97.

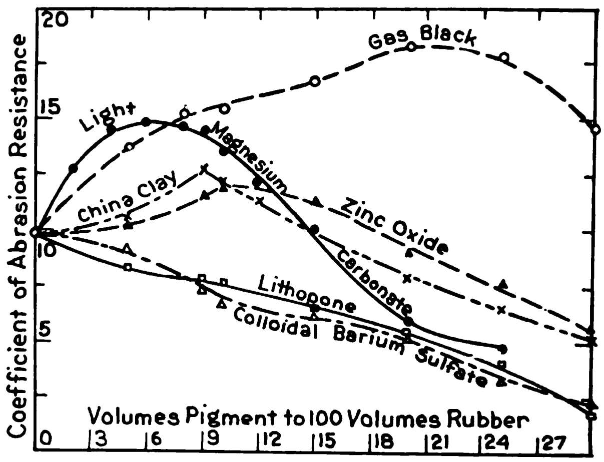


Fig. 98.

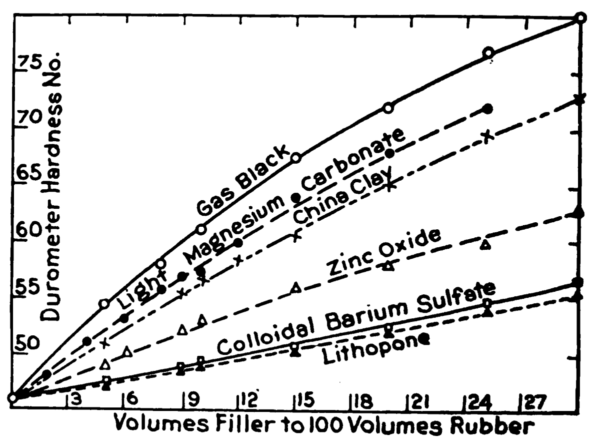


Fig. 99.

Figures 100–102 illustrate the influence on the load-strain relations, ultimate tensile strength and energy of resilience of various proportions of MR (mineral rubber, prepared from blown asphalt and gilsonite) (solid lines), and of carbon black (dotted lines) added to the basal stock (rubber, 100; S, 10) (115). Figs. 100, 102: cured at 141° for 165 min; Fig. 101: cures giving maximum tensile strength.

Figure 103 illustrates the influence on the sub-permanent set of various proportions of barytes, carbon black, MR and ZnO added to the basal stock (rubber, 100; S, 10) (115).

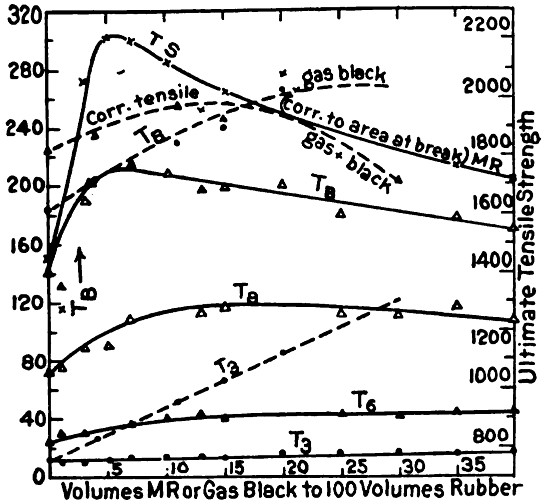


FIG. 100.

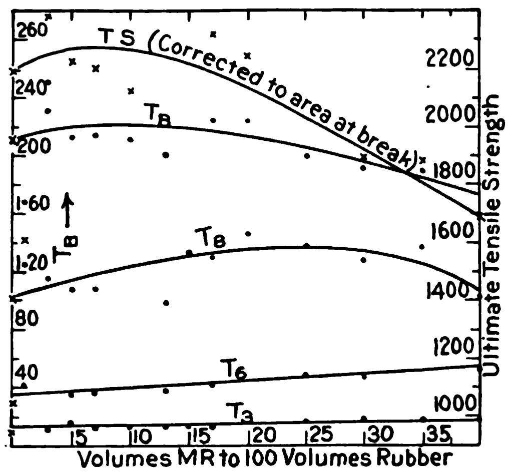


FIG. 101.

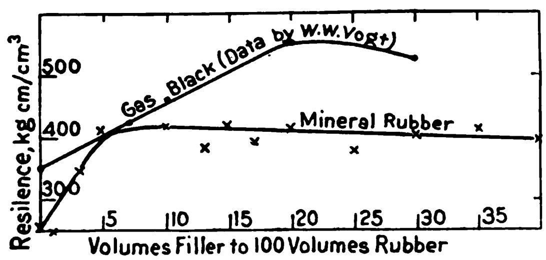


FIG. 102.

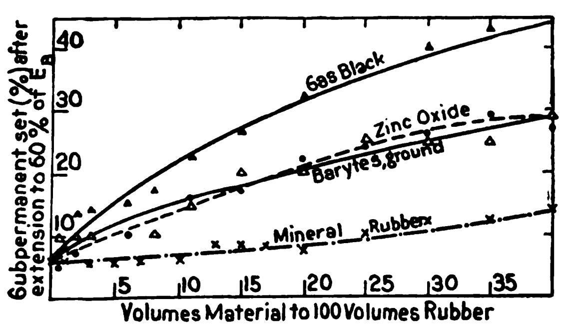


FIG. 103.

BROWN FACTICE

Rubber substitute, vulcanized oil

TABLE 135.—EFFECT ON VULCANIZED RUBBER (4)

Stock: rubber, 100; S, 7.5; ZnO, 5; diphenylguanidine, 0.5; vulcanized 45 min at 135°

Brown factice, parts	T_B	E_B	T_7
0	180	748	147
1	171	746	136
5	170	738	124
10	162	791	106
40	102	698	103
40*	60	571	

* Also contained 9 parts "light" $MgCO_3$; vulcanized 60 min at 142°.

BROWN FACTICE, "GOLDEN" ANTIMONY SULFIDE AND IRON OXIDE

TABLE 136.—EFFECT OF BROWN FACTICE WHEN USED WITH ANTIMONY SULFIDE OR IRON OXIDE (5)

Composition of stocks

Stock	Rubber	S	Brown factice	Antimony sulfide (3 % free S)	Iron oxide
A	76.5	8.0		15.5	
B	76.5	8.5			15.5
C	59.5	8.0	17.0	15.5	
D	59.5	8.5	17.0		15.0

Tensile properties after vulcanization at 141°

Stock	A		B		C		D	
Cure, min	T_B	E_B	T_B	E_B	T_B	E_B	T_B	E_B
75					89	738		
90	113	733			104	724	88	734
120	121	707			90	640	109	700
150	123	706	124	777			106	600
165			134	752				
175			136	768				
180	132	654			4	301		
190			134	731			64	514
205			134	709				
210	83	510						

CLAY

Effect of adsorptive power (defined as % of dye adsorbed by 2 g of clay from 50 cm³ of 0.1 % malachite green solution) on the properties of rubber.

TABLE 137 (159)

Stock: rubber, 48.375; clay, 21; ZnO, 11; lithopone, 17; S, 2; diphenylguanidine, 0.625; vulcanized at 145° (cure giving maximum tensile strength)

Sample No.	1	2	3	4	5	6	7
Adsorptive power, %	40.14	47.6	56.2	89.7	89.9	99.2	99.5
Cure, min	20	20	20	20	20	50	40
T_B	174.3	170.1	167.3	140.6	140.6	106.8	87.9

TABLE 138 (159)

Stock: rubber, 63.496; clay, 26; ZnO, 5.5; MgO, 2.0; S, 2.5; diphenylguanidine, 0.504; vulcanized at 153° (cure giving maximum tensile strength)

Sample No.	Mean size, microns	Adsorptive power, %	Cure, min	T_B
1	3.3	40	15	232.7
2	3.3	59	20	232
3	3.3	75	20	225

TABLE 138 (159).—(*Continued*)

Sample No.	Mean size, microns	Adsorptive power, %	Cure, min	T_B
4	5.0	75	20	214.4
5	3.2	77	20	228.2
6	3.2	81	25	208.1
7	3.9	82	20	224.3
8	3.3	82	30	220
9	2.9	85	25	200.3
10	3.7	100	40	161
11	4.4	100	40	117.4

CARBON BLACK

TABLE 139.—EFFECT OF DIFFERENCES IN SAMPLES OF CARBON BLACK ON THE PROPERTIES OF RUBBER* (149)

Stock A: rubber, 73.5; carbon black, 19.06; ZnO, 4.33; S, 1.84; diphenylguanidine, 1.27. Stock B: rubber, 72.83; carbon black, 18.80; ZnO, 4.25; S, 3.60; hexamethylenetetramine, 1.12.

	Cure giving maximum T_B					
	Stock A			Stock B		
	Mean	Max.	Min.	Mean	Max.	Min.
Cure, min	36	55	25	68.5	75	60
T_5	165	244	97	154	238	85
T_B	346	379	310	298	320	278
E_B	703	790	604	673	737	590

* 18 samples of carbon black were used with stock A, and 7 with stock B. For details as to their properties, v. (149).

RECLAIMED RUBBER AS A COMPOUNDING INGREDIENT

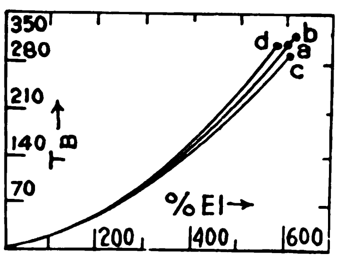


FIG. 104.

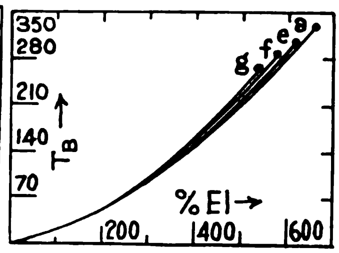


FIG. 105.

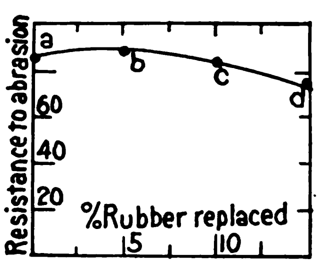


FIG. 106.

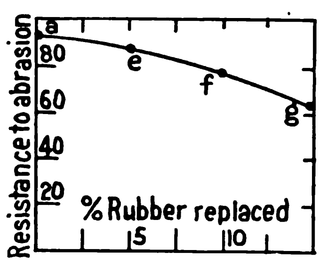


FIG. 107.

TABLE 140.—VULCANIZATION OF RECLAIMED RUBBER (16)

Whole black tire reclaim (alkali process): sp. gr., 1.18; acetone extract, 7.5%; ash, 20%

Composition				Vulcanized at 142°		
Rubber	S	ZnO	Diphenylguanidine	Cure, min	T_B	E_B
100	5	0	0	20	54.8	410
100	5	0	0	30	59.8	450
100	3	3	0.5	20	93.5	400
100	3	3	0.5	30	80.9	320

TABLE 141.—COMPOSITION OF STOCKS CONTAINING RECLAIMED RUBBER, SHOWING POSSIBLE VARIATIONS IN THE AMOUNTS OF ZnO AND CARBON BLACK USED

For load-strain curves and resistance to abrasion, *v.* Figs. 104–107 (16)

	Original stock*	Reclaimed rubber content increased, with decrease:					
		Of ZnO			Of carbon black		
Sample	a	b	c	d	e	f	g
Rubber	60	57	54	51	57	54	51
Reclaim†	0	6	12	18	6	12	18
ZnO	12	8	4	0	13	14	15
Carbon black	24.1	25.1	26.1	27.1	20.1	16.1	12.1

* Contained also: S, 2.4; ethylidineaniline, 0.45; diphenylguanidine, 0.45; stearic acid, 0.3; mineral oil, 0.3. † For properties of the reclaimed rubber, v. Table 140.

AGING

TABLE 142.—EFFECT OF AGE ON THE VULCANIZATION OF RAW RUBBER

Stored in the tropics (53); *cf.* Tables 24, 144; stock: rubber, 90; S, 10

Type	Number of samples	Mean age, mo	Mean time of cure (min) at 141°		Mean tensile product ($T_B \times E_B/1000$)	
			Initial	After aging	Initial	After aging
Slab crepe	23	34	76.3	106.3	129.8	100.5
Crepe	35	34.5	172	138	118.1	105.7
Sheet	27	34.5	135	120	129.1	110.8

TABLE 143.—AGING OF CEYLON BLANKET CREPE (154)

	Air-dried*		Heat-dried*	
	Initial	After 2 yr	Initial	After 2 yr
Cure, min	127	116	135	130
T_B	145	141	140	132
Slope	34.5	35	35.5	36.5
η, 1% in C_6H_6†	39.5	26.5	23.5	17.5
η, 1% in C_6H_6 + HCl†		15		12

* Two samples. † Viscosity relative to that of solvent.

TABLE 144.—AGING OF SLAB CREPE (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150°; aged 4 yr in tropics

	Slab crepe	Latex crepe (control)
Number of samples	6	3
% H_2O	0.41	0.34
% ash	0.34	0.20
% aqueous extract	0.45	0.28
Cure, min, initial	39.5	107
Cure, min, aged	57	105
T_B, initial	146	146
T_B, aged	133	148
Slope, initial	34	36
Slope, aged	34	36
η, relative, initial	102	39
η, relative, aged	23	31

TABLE 145.—AGING OF PURE GUM STOCK AT ROOM TEMPERATURE*

Influence of % of S (200)

Stock A: rubber, 90; S, 10; vulcanized 80 min at 148°

Age, da	T_B	E_B	E_{130}
3	129	906	907
111	142	873	853
181	136	851	842
380	135	821	816
495	149	821	790
619	137	795	784

Stock B: rubber, 92.5; S, 7.5; vulcanized 105 min at 148°

Age, da	T_B	E_B	E_{130}
3	134	930	923
113	144	900	877
181	144	886	863
376	136	836	827
495	137	810	800
619	115	769	793

Stock C: rubber, 95; S, 5; vulcanized at 148°

Cure, 140 min				Cure, 200 min				Cure, 300 min			
Age, da	T_B	E_B	E_{130}	Age, da	T_B	E_B	E_{130}	Age, da	T_B	E_B	E_{130}
3	110	987	1023	3	131	952	950	3	105	969	1019
111	126	960	967	111	143	918	898	108	116	944	970
216	129	953	954	181	139	898	883				
430	121	889	905	376	51	581		423	12	381	
550	116	869	895	457	14	380		532	10	333	
673	93	899	856	567	13	314					

* *Ca.* 27° (in tropics).

TABLE 146.—ACCELERATED AGING OF PURE GUM STOCK AT 65° (180)

Influence of degree of vulcanization; stock: rubber, 92.5; S, 7.5; vulcanized at 148°

Age, da	Cure, 70 min			
	T_B	E_B	E_{90}	V. C.
0	86.5	1053	1115	1.98
1	75	1009	1052	
2	85	998	1010	
3	92	982	976	2.42
4	93	965	958	
6	94.5	952	943	2.30
9	95	926	912	
16	98	903	885	2.70

Age, da	Cure, 90 min				Cure, 110 min			
	T_B	E_B	E_{130}	V. C.	T_B	E_B	E_{130}	V. C.
0	91	984	1060	2.82	128.5	943	950	3.89
1	103	949	998		134	919	915	
2	110	937	973		137	901	889	
3	106	914	956	3.24	139.5	888	872	4.07
4	119	907	925		136.5	858	848	
5	129	912	924	2.96	141.5	853	835	4.02
7	125.5	900	907		143	848	825	
12	104.5	833	878	3.74	104	722		4.27

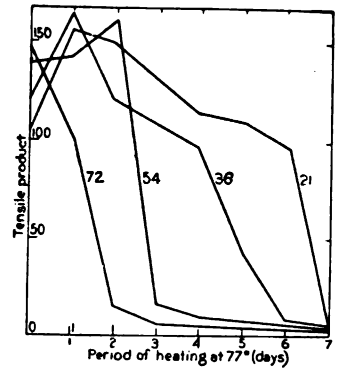


FIG. 108.—Accelerated aging of pure gum vulcanized rubber. Influence of degree of vulcanization on the tensile product of the stock. Basal stock: rubber, 100; S, 8; vulcanized at 143° (111). The figures on the curves denote the time (in min) of vulcanization at 143°.

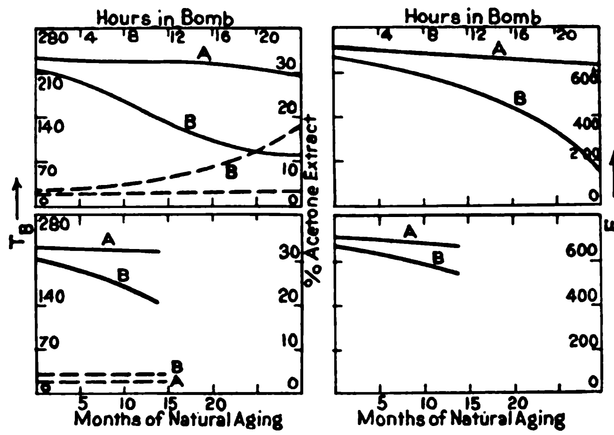
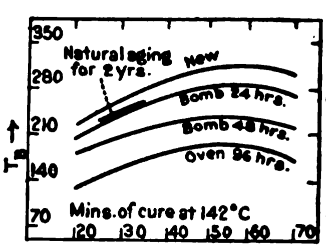


FIG. 109.—Comparison of aging of some compounded stocks in the dark at room temperature with aging accelerated by heating at 60° in oxygen at a pressure of 21 kg/cm² (straight test pieces) (15). Stock A: rubber, 100; S, 4; diphenylguanidine, 0.5; pptd. whiting, 50; ZnO, 4; vulcanized 30 min at 142°. Stock B: rubber, 100; S, 6; PbO, 10; pptd. whiting, 50; vulcanized 25 min at 142°.



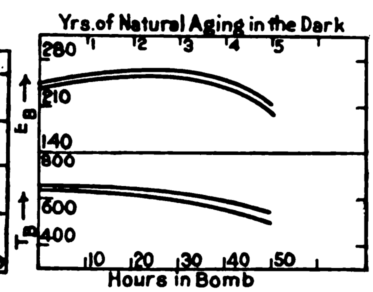


FIG. 110. FIG. 111.

FIG. 110.—Same as Fig. 109. Stock: rubber, 100; S, 1; tetramethylthiuram disulfide, 1; ZnO, 100; vulcanized 10 min at 134° (15).

FIG. 111.—Comparison of aging in the dark at room temperature, accelerated aging at 60° in oxygen at 21 kg/cm², and accelerated aging at 70° in a current of air at atm. pressure in the case of a tire tread stock vulcanized for various periods (15). Stock: rubber, 60; S, 3; diphenylguanidine, 0.5; ethylideneaniline, 0.375; pine tar, 1; ZnO, 17.125; carbon black, 18. For further data on the aging of compounded stocks, especially low-grade stocks, *see* (33).

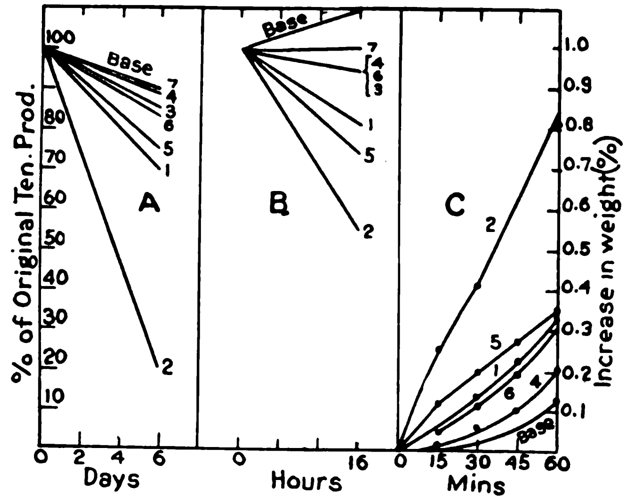


FIG. 112.—Influence of compounding ingredients on accelerated aging. Basal stock: rubber, 100; ZnO, 5; S, 4; diphenylguanidine, 0.75. Other stocks prepared by adding 20 vols. of the following to 100 vols. of rubber: (1) barytes; (2) carbon black; (3) clay; (4) $MgCO_3$; (5) thermatonic carbon; (6) whiting; (7) ZnO [173]. (A) Effect on the tensile product of heating the best technical cure (30–45 min at 141° for all stocks except 4 (15 min) and 2 (60 min)) for 6 days in a current of air at atmospheric pressure and 70°. (B) Effect on the tensile product of heating the best technical cure for 16 hr in oxygen at 28 kg/cm² and 60°. (C) Increase in weight as in (B) of the vulcanizates obtained by various periods of cure (mins denote period of vulcanization at 141°).

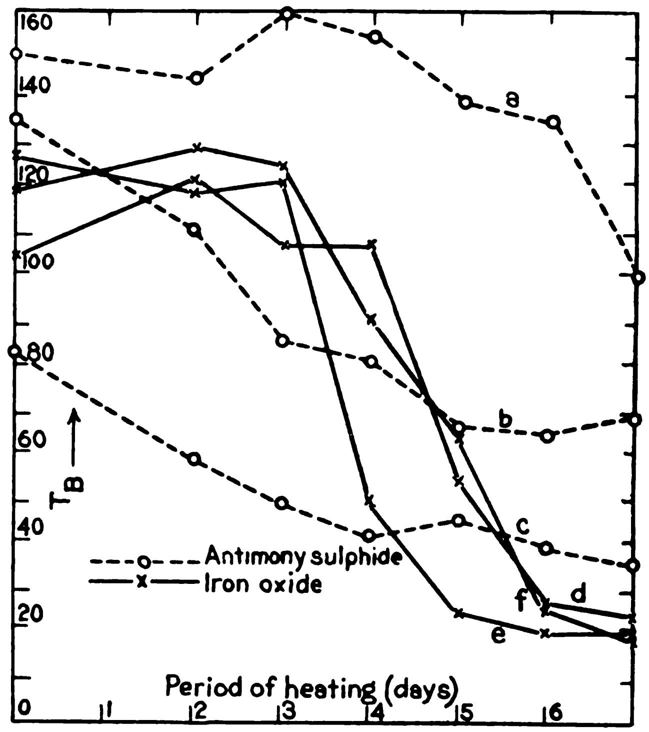


FIG. 113.—Change in tensile strength on accelerated aging at 70° in a current of air at atmospheric pressure of stocks containing (A) Fe_2O_3, (B) Sb_2S_3. Stock A: rubber, 76.5; S, 8.5; Fe_2O_3, 15. Stock B: rubber, 76.5; S, 8; "golden" Sb_2S_3 (3 % free S), 15.5. Vulcanized at 141° (a), 2 hr; (b) and (d) 2.25 hr; (c) and (f), 2.5 hr; (e) 2.75 hr [5].

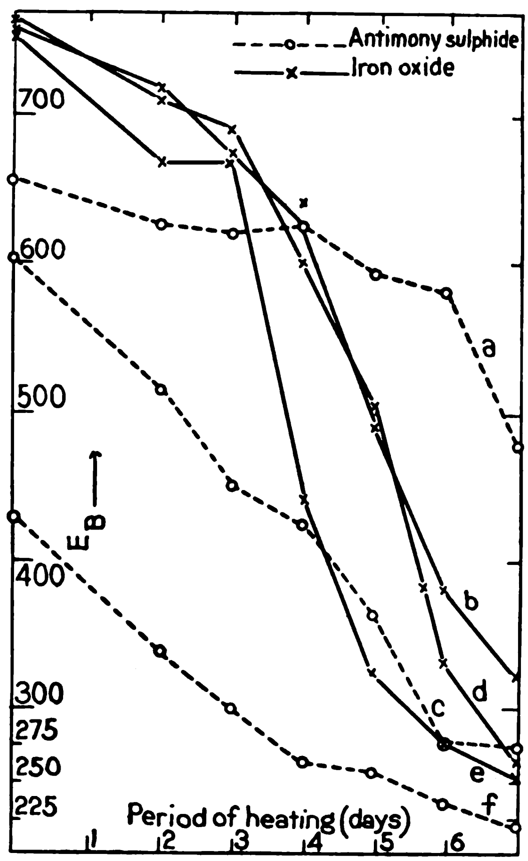


FIG. 114.—Change of ultimate elongation on aging as in Fig. 113 [5].

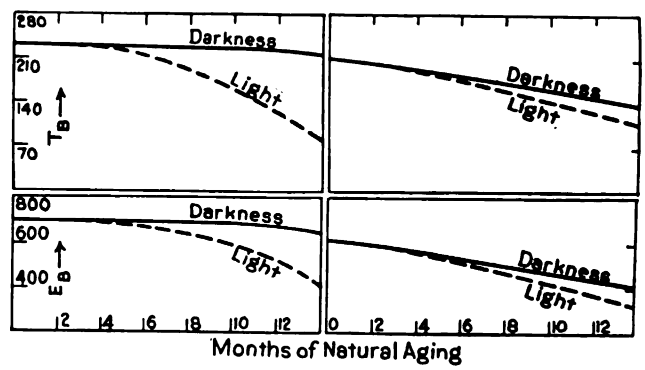


FIG. 115.—Influence of light on aging at room temperature. Curve marked "light" is for rubber behind glass in a very light room [15]. Stock (left-hand curves): rubber, 100; S, 4; ZnO, 4; diphenylguanidine, 0.5; pptd. whiting, 50; (right-hand curves): rubber, 100; S, 6; litharge, 10; pptd. whiting, 50 (*cf.* Fig. 109).

HARD RUBBER

Commercial Samples.—T_B = 105–700; E_B = 2–75; compressive strength = 210–1400 kg/cm²; sp. gr. = *ca.* 1.20 (mean) [33].

Electrical Properties.—*v.* Tables 105–110.

Coefficient of Thermal Expansion.—80 × 10^{-6} (20–60°) [148].

Specific Gravity.—*v.* commercial samples and Tables 105, 106, 110.

TABLE 147.—INFLUENCE OF DEGREE OF VULCANIZATION ON SP. GR. (70)

Stock A: rubber, 70; S, 30. Stock B: rubber, 70; S, 30; diphenylguanidine, 1.4. Both vulcanized at 170°

Cure, min	Sp. gr.	
	Stock A	Stock B
15	1.076	1.163
45	1.162	1.174
75	1.167	1.176

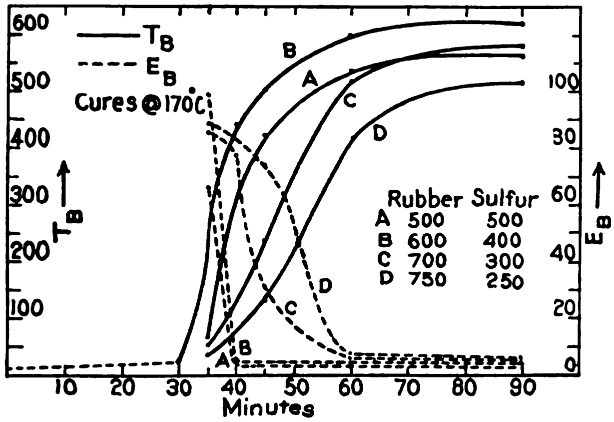


FIG. 116.—Vulcanization of pure gum hard rubber stocks. Influence of the proportions of S on the progressive change in tensile properties (69). Stocks containing rubber and S in the ratios indicated vulcanized at 170°.

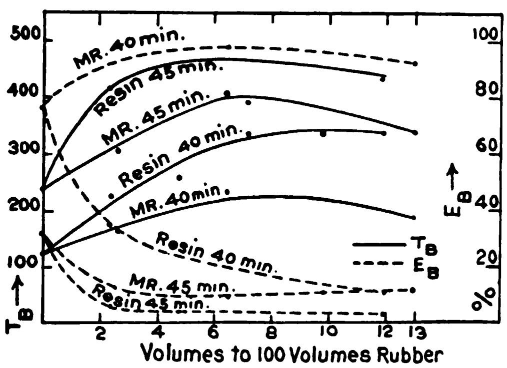


FIG. 118.—Influence of various proportions of MR (mineral rubber) and resin on tensile properties of hard rubber (basal stock: rubber, 70; S, 30 by wt.) vulcanized 40 and 45 min at 170° (straight test pieces) (69).

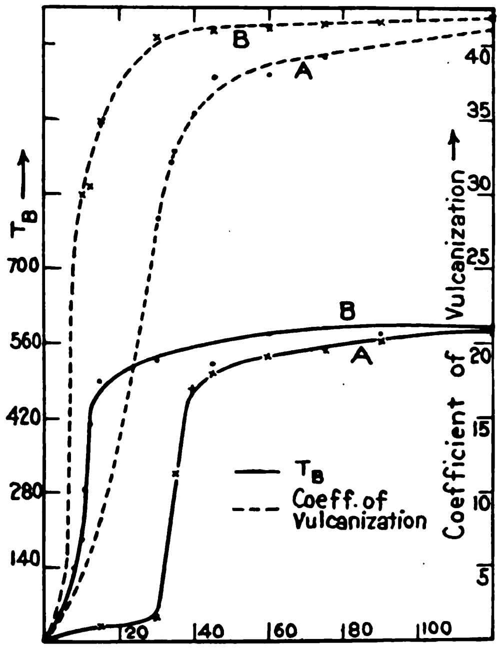


FIG. 117.—Tensile strength and vulcanization coefficients of pure gum hard rubber stocks vulcanized for various periods at 170°. Stock A: rubber, 70; S, 30. Stock B: rubber, 70; S, 30; diphenylguanidine, 1.4 (70). Data are also given in this article for other accelerators.

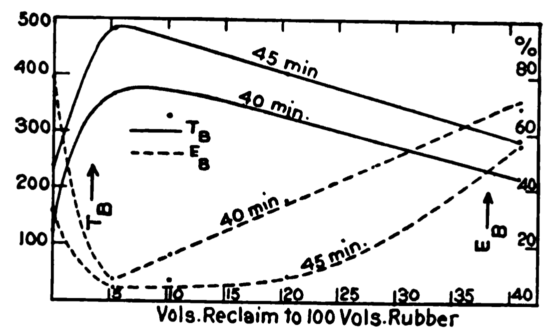


FIG. 119.—Influence of various proportions of tire reclaim on the tensile properties of hard rubber (basal stock: rubber, 70; S, 30) vulcanized 40 and 45 min at 170°.

TABLE 148.—EFFECT OF HEATING ON THE SOFTENING TEMPERATURE, IMPACT STRENGTH AND TRANSVERSE STRENGTH AND THE INFLUENCE OF VULCANIZATION CONDITIONS ON THE IMPACT STRENGTH (46)

Stock A: rubber, 71.43; S, 28.57; vulcanized 12 hr at 149° (3 hr rise). Stock B: rubber, 70.42; S, 28.17; diphenylguanidine, 1.41; vulcanized 12 hr at 149° (3 hr rise). Stock C: rubber, 70.42; S, 28.17; diphenylguanidine, 1.41; vulcanized 2 hr at 149° (1 hr rise). Test bars: 7.5 × 1.25 × (4.75–6.25) cm.

	Stock	Initial	After heating in air								
			At 70°		At 149°						
			7 da	14 da	5 hr	10 hr*	15 hr*	25 hr*	40 hr*	60 hr*	60 hr†
Softening temperature, °C‡	A	77.8	91.7	91.1	78.3			82.8			
	B	80	87.8	90	82.8	87.2	82.2	82.2	73.9	67.2	
Transverse strength (kg/cm²)§	A	857.8	1040.4	1047.5	984.3			991.2		485.1	
	B	822.4	1061.3	1040.3	1019.2	1064.4	998.2	984.1	534.2	400.7	
Impact strength (kg cm/cm²)‖	A	41.1	41.26	25.72	19.13			6.40		2.32	5.71
	B	47.70	21.61	30.37	10.90	19.49	13.40	7.14	3.99	2.32	3.57
	C	71.64	25.37	25.01	9.47			5.36		1.43	2.32

* Heating intermittent: 5 hr daily on successive days.
† Heating continuously.
‡ Under the load at which excessive flow begins; 5 cm between supports.
§ Dead load producing rupture; 5 cm between supports.
‖ 6.25 cm between supports.

GUTTA-PERCHA AND BALATA

TABLE 149.—CHEMICAL COMPOSITION, SOFTENING POINT, TENSILE PROPERTIES AND ELECTRICAL PROPERTIES OF GUTTA-PERCHA [116]

		Number of samples	Chemical composition, %				Softening		Hardening time, min	T_B	E_B	Insulation at 24°, megohm	Inductive capacity microfarad
			Gutta	Resin	Dirt	Water	Begins at t, °C	Pliable at t, °C*					
Genuine	Pahang	40	78.1	19.2	1.5	1.2	47.7	65.5	3.33	322	427	2 408	0.0535
	Banjer red	70	67.0	30.2	1.5	1.3	43.8	66.1	6.75	252	384	6 400	0.0559
	Bulongan red	22	68.6	29.0	1.4	1.0	45.5	63.3	8	250	419	7 643	0.0552
Soondie	Bagan	21	57.5	40.9	1.0	0.6	40.0	61.6	9.5	172	379	5 728	0.0524
	Kotaringin Goolie red	48	55.2	42.9	1.2	0.7	39.4	60.5	20	148	372	3 739	0.0563
	Serapong	31	56.2	42.4	0.9	0.5	40.5	60.5	15.75	167	391	33 590	0.0537
White	Bulongan	7	52.2	45.4	1.5	0.9	41.1	67.7	23.5	172	426	44 220	0.0570
	Mixed	8	49.8	47.4	1.1	1.7	42.7	76.1	21.5	179	364	67 800	0.0606
	Banjer	9	51.8	44.1	1.8	2.3	42.2	73.3	28.5	204	409	50 060	0.0624
Medium quality cleaned			54.7	39.4	2.7	3.2	37.7	58.8	17	112	360	34 970	0.0613
Medium quality hardened by extracting resin			93.0	2.8	2.5	1.7	57.2	91.1	0.75	399	285	27 410	0.0575

* Temperature at which a strip 70 mm × 25 mm × 2 mm tears under a load of 14.2 g.

TABLE 150.—CHEMICAL COMPOSITION OF BALATA [87]

		Chemical composition, %			
		Gutta	Resin	Dirt	Water
Commercial	Brazilian block	46.7	38.7	3.4	11.2
	Prime Amazonian	45.9	35.9	2.8	15.4
	Iquitos	46.2	46.0	0.4	7.4
	Demerara	42.6	48.0	3.7	5.7
Cleaned balata		52.6	45.3	0.54	1.57

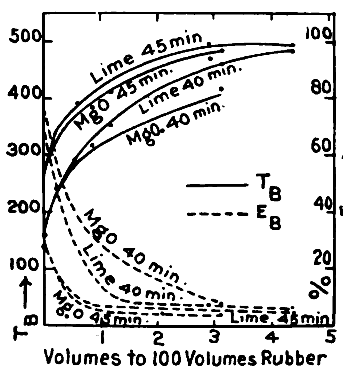


FIG. 120.—Influence of various proportions of lime and magnesia on the tensile properties of hard rubber (basal stock: rubber, 70; S, 30 by wt.) vulcanized 40 and 45 min at 170° (straight test pieces) [69].

TABLE 151.—PROPERTIES OF LEAF GUTTA-PERCHA [171]

	Number of samples	Chemical composition, %				Surface resistivity* at 5 000 – 10 000 volt, ohm	Dielectric strength, kv-cm
		Gutta	Resin	Dirt	Water		
Tjipetir	2	77.2	6.85	11.55	4.3	0.5 to 14 × 10^{11}	210 to 310

* Tests with 6 sheets of different thicknesses.

For further data on electrical properties, *v.* Tables 96–99.

Chemical Character of the Resin of Gutta-Percha

Saponification No. (4 samples), 79.8 to 77.3; acid No. (4 samples), 5.0 [14]. Contains:

Fluavile, amorphous, molten at 100°, $C_{20}H_{32}O$ [119], or $C_{40}H_{64}O_3$ [116], soluble in cold alcohol.

Albane, M. P. *ca.* 160°, $C_{20}H_{32}O_2$ [119], soluble in boiling alcohol, insoluble in cold alcohol.

Nitrogen content of Gutta-Percha, 0.83 % [150].

Physical Properties of Gutta-Percha and Balata

Refractive index, 1.52 [108].

Specific heat at 4.5°, 0.402 g-cal/g [88].

Linear expansion (2.4 to 5.8°), 0.0001575 cm per °C [88].

Specific gravity [116].

	Gutta-Percha (leaf)	Gutta-Percha	Gutta-Percha	Gutta-Percha	Balata
Number of samples	1	3	3	3	
Gutta/resin ratio	5.19	3.8	1.37	1.37	
Sp. gr., mean	0.9625	0.9879	0.9735	1.0063	0.9731

TABLE 152.—SOFTENING POINT AND VISCOSITY OF GUTTA-PERCHA [48]

	% composition		Softening point, °C	Viscosity (2 % soln. in CCl_4)
	Gutta	Resin		
Tjipetir	74.98	11.09	60	1.60
White	49.10	48.65	50	1.44
Salai prima	33.76	48.58	47	1.59
Gulai sekunda	29.54	55.39	37	1.33
Akassa	12.83	73.19	42	1.41
Siak	14.34	69.50	35	1.02
Penang	20.41	65.12	40	1.12

TABLE 153.—EFFECT OF COMPOUNDING INGREDIENTS ON THE SOFTENING TEMPERATURE OF GUTTA-PERCHA [49]

Sample of Gutta-Percha contained 55.39 % resin

Ingredient	None	Kieselguhr	Barytes	MgO	
% ingredient	0	100	70	100	140
Softening temperature	38°	55°	44°	65°	84°

Water Absorption by Gutta-Percha

TABLE 154.—OSMOTIC PRESSURE AND MOLECULAR WEIGHT OF GUTTA-PERCHA [36]

C_6H_6 soln. of washed and de-resinified Gutta-Percha

% concentration	Osmotic pressure, atm.	Molecular weight
6.03	0.0500	29 500
3.04	0.0238	31 100
2.04	0.0146	34 000
1.26	0.0086	35 600

TABLE 155.—RATE OF COMBINATION OF S ([153])

Time, hr	Combined S, %	
	Gutta-Percha	Balata
2	3.12	
5		9.43
8	14.12	13.27
15		25.61
25	31.95	31.89
30	31.97	31.85

TABLE 156.—VULCANIZATION OF MIXTURES OF RUBBER AND GUTTA-PERCHA ([87])

Composition			Vulcanization at 148°									
Rubber	Gutta-Percha	S	45 min		60 min		75 min		90 min		120 min	
			T_B	E_{50}	T_B	E_{50}	T_B	E_{50}	T_B	E_{50}	T_B	E_{50}
90	0	10	74	885	120	813	143	766	157	715	170	715
88	2	10	49		93	915	111	830	135	788		
86	4	10	72	900	100	865	112	817	170	750		
80	10	10	60	893	133	865	159	810	158	748		

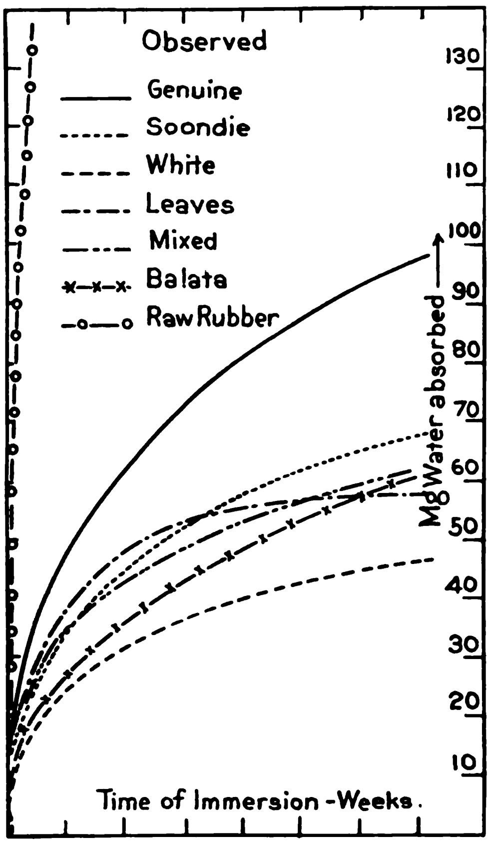


FIG. 121.—Water absorption (in mg) of different classes of Gutta-Percha and of balata. Thickness of sheet 2.2 mm, area 100 cm², wt. 10 g ([116]).

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(For a key to the periodicals see end of volume)

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FACTITIOUS PLASTICS

A. NITROCELLULOSE ("PYROXYLIN") PLASTICS[1]

Made by the application of heat and pressure to colloidal mixtures of pyroxylin with relatively non-volatile solvent (camphor or substitute for camphor) and volatile solvent (usually ethyl alcohol), followed by evaporation of the volatile solvent; ordinarily containing sufficient non-volatile solvent to insure "plasticity" at 75–90°C—*e.g.*, celluloid, fiberloid, pyralin, pyradiolin, viscoloid, xylonite.

Except as otherwise noted, the data given are for the freshly manufactured, commercial type of camphor product. Photographic film is not covered.

1. *Composition.*—Varies according to manufacturer. The following are illustrations:

PYRALIN (7)

Pyroxylin 11% N	Camphor	Stabilizer	Residual volatile solvent	Additions: dyes, pigments, etc.
68–75%	23–27%	0.5–1%	1–5%	0–14%

VARIOUS FOREIGN AND DOMESTIC SAMPLES (21)

Nitrocellulose	Camphor + solvent	Ash
58–78%	17–31%	0.7–28%

[1] Acknowledgment is made to Mr. A. F. Randolph, du Pont Viscoloid Company, for a critical examination of this section.

Mechanical

2. *Density.*—g cm^{-3}. 1.35 (transparent) to 1.60 (commercial pigmented material)(7). $d = 1.37 + 0.0125p$, where $p = \%$ ZnO between 1 and 15 (14). For influence of stretching *v.* (16).

3. *Permeability.*—Transparent material of thickness 0.030 in., exposed on one surface to atmosphere dried by $CaCl_2$ and on other side to summer atmosphere, transmitted moisture at rate of 0.013 g per in.^{2} per week (7).

Pyralin, from saturated air to air dried by $CaCl_2$, 0.0046 resp. 0.063 in. thick, transmitted moisture at the rate of 0.029 resp. 0.004 g in.$^{-2}$ day^{-1} in three days (7).

4. *Modulus of Elasticity* (Def. 10*a*).—Young's modulus = (2.0 to 3.9) $\times 10^5$ lb. in.$^{-2}$ (5, 7, 11, 12, 16, 17). Exhibits hysteresis (13).

5. *Elastic Limit.*—Yield point = (3.9 to 7.4) $\times 10^3$ lb. in.$^{-2}$. Varies with thickness and pigment content (5, 7, 12, 16).

6. *Poisson's Ratio.*—0.36 to 0.43 (5, 11).

7. *Tensile Strength* (Def. 4).—Varies with thickness, nature of nitrocellulose, camphor content, and pigment content. (4.9 to 8.5) $\times 10^3$ lb. in.$^{-2}$ (7, 11, 12); 6 kg mm^{-2} (5). Variation with temp. °C; 20°, 7.5; 70°, 4.5; 90°, 1.0; $\times 10^3$ lb. in.$^{-2}$ (7).

8. *Ultimate Elongation at Failure.*—From 10% for 0.005 in. thick up to 40% for 0.2 in. thick; for 0.015 in. thick, from 20 to 30% for 0 pigment, to 15 to 25% for 16% pigment (7), *cf.* (4, 5).

9. *Resistance to Bending.*—Schopper's folding endurance tester. Sample 0.5 $\times$ 4.0 $\times$ 0.015 in., double bends of 100° required to break (B_D) = 8 to 22. $B_D = k \times (\text{thickness})^{-1.35}$ (7).

10. *Hardness.*—Brinell, 10.7 to 11.7 [20]. H = const. − (0.05 × % ZnO), approx. between 1 and 15 %. Method of penetration by loaded sphere [14].

11. *Coefficient of Friction.*—Static, of polished material on self, glass, paper, or planed wood, 0.25 to 0.35 [7].

12. *Viscosity.*—Solutions in camphor-alcohol [15].

Thermal

13. *Thermal Expansion.*—$\frac{1}{l}\frac{dl}{dt}$ (20–50°C) = (12 to 16) × 10^{-5} [19, 20].

14. *Heat Capacity* (*Specific Heat*).—0.34 to 0.38 cal g^{-1} $°C^{-1}$ [20].

15. *Thermal Conductivity.*—Cal cm^{-2} sec^{-1} $(°C, cm^{-1})^{-1}$. 3.1 × 10^{-4} [20]. 5.14 × 10^{-4} [22, 27].

16. *Working Range for Molding.*—85 to 120°C [7].

17. *Permanent Shrinkage on Heating.*—1.4 % after two heatings to 100° in air [18]; 0.5–1 % [7]. Variable, depends on amount of internal strain.

18. *Flash Point.*—141 to 185°C for 0.3 g of powder heated 3° per min [15]. 160 to 200°, for material of good quality [7, 9]. 550 to 640° for edge contact with hot porcelain rod [21].

19. *Loss in Weight at 110°.*—Very variable [7, 9], *cf.* [21].

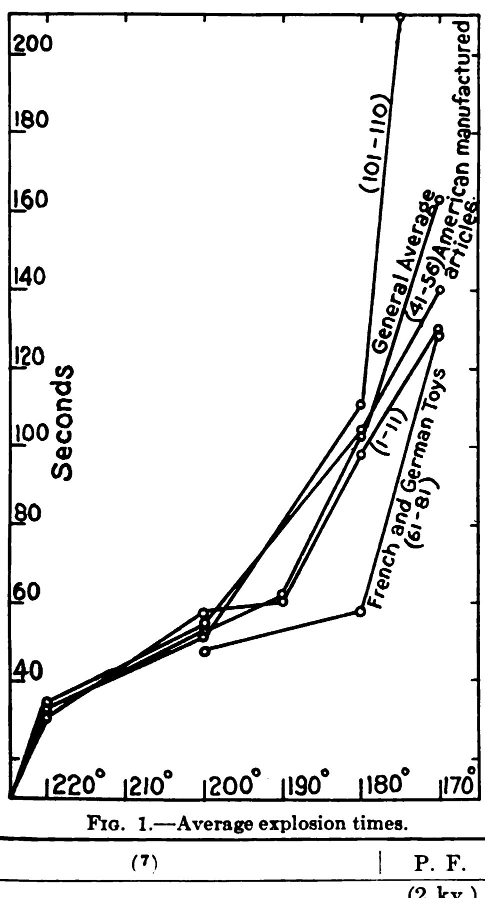

FIG. 1.—Average explosion times.

20. *Explosion Times.*—[21]. For improved method of test, *v.* [24].

Time in seconds	Temperature of metal, °C	Transparent pyralin A	Transparent pyralin B	Pyradiolin A	Pyradiolin B
(A) to the start, (B)	215	63	65	300	330
to the finish, of	225	59	61	58	85
fuming-off or burn-	235	39	42	50	65
ing of 0.5 × 0.5 ×	250	22	24	36	47
0.06 in. samples	275	10	15	12	30
thrown on surface	300	4	13	15	27
of molten metal	350	3.5	9	8	20
[7].					

21. *Rate of Combustion.*—For thin strips, 5 to 10 times that of thin paper or wood shavings of same dimensions [21]. For composition of gases produced *see* [21, 25]. Pyradiolin, vertically upward about ⅓ that of pyralin; horizontally or vertically downward, 0 if flame is removed after ignition [7].

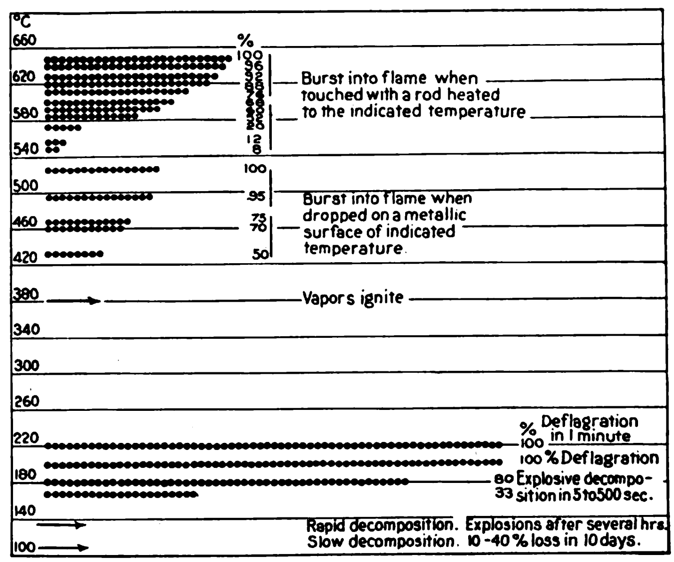

FIG. 2.—Behavior of celluloid at various temperatures.

Electrical

22. *Electrical Resistivity.*—Volume resistivity, R_v = (2 to 30) × 10^{10} ohm-cm. Surface resistivity, R_s, at 50 % humidity, *ca.* $3R_v$; at 85 % humidity, *ca.* $0.2R_v$ [3].

[7]	R_v in 10^{10} ohm-cm			R_s in 10^{10} ohm 400 v	
Material	At 500 v 20°C	50 % humidity	Water-soaked	50 % humidity	Water-soaked
Transparent pyralin	98	7.2	6.6	>10^4	36
Pyradiolin	2350	2200	840	>10^4	600
Source	E. T. L.	Cruft Lab., Harvard			

23. *Phase Difference* (*Power Factor*).—In circular degrees, 3.0 to 4.6° at 6 × 10^5, 2.5 to 5.3° at 10^5 cycles sec^{-1} [3].

[7]	P. F.	Phase angle, circular degree							
Kilocycles sec^{-1} =	(2 kv.) 0.06	1	5	20	100	500	2000	1	
Transparent pyralin	2.5%	0.0301	0.026	0.0273	0.0305	0.0350	0.043	0.034*	0.034†
Pyradiolin	4.0%	0.0365	0.041	0.0402	0.0340	0.0289	0.025	0.036*	0.038†
Source	E. T. L.	Cruft Lab., Harvard							

* = at 50 % humidity. † = water-soaked.

24. *Dielectric Constant.*—6.9–8.8 at 6×10^5 cycles sec^{-1}; 7.2–9.8 at 10^5 cycles sec^{-1} ([3]); 12 at 40 cycles ([1]).

([7])	(2 kv.)	* = at 50% humidity. † = water-soaked							
Kilocycles-sec^{-1} =	0.06	1	5	20	100	500	2000	1	
Transparent pyralin	6.3	7.00	6.78	6.59	6.38	6.19	5.98	7.2*	7.2†
Pyradiolin	5.6	5.65	5.42	5.23	4.97	4.79	4.58	5.7*	5.8†
Source	E. T. L.	Cruft Lab. Harvard							

25. *Dielectric Strength.*—Averages of 10 determinations using blunt needle-point electrodes under oil. Source: E. T. L. ([7]).

Material	Thickness, mils	Volts per mil
Pyralin:		
Black	60	780
Black	215	230
Transparent	23.4	900
Transparent	63.6	475
Transparent	91	270
White	211	210
Green transparent	200	225
Yellow transparent	64	635
Pyradiolin	59	780
Pyradiolin	60	750

Optical

26. *Refractive Index.*—$n_D = 1.46 \pm 0.03$ ([7]).

27. *Birefringence.*—Celluloid under tension exhibits birefringence. The *specific birefringence*, $\frac{N_E - N_O}{\%E}$, for Na light (where E is the elongation and N_E, resp. N_O, the refractive indices for the extraordinary and ordinary ray resp.), is 0.046 for 0% camphor and decreases to 0.005 for 50% camphor. For constant tension it increases with time. Data *in re* the after effects of tension on birefringence, density, and dispersion are also given in ([5, 10, 11, 16]).

28. *Coefficient of Absorption.*—$I = I_0 l^{-kt} = 1.81$ and 1.95, two samples (Na light) ([11]). Cellulose acetate transmits the ultraviolet down to 230$\mu\mu$ ([13]).

Chemical

29. *Chemical and Solvent Action of Various Reagents.*—A, Little or no effect at room temperature. B, Superficial attack, blistering or softening. C, Gelatinization. D, Solution with decomposition. E, Good solvent. F, Not solvent, but becomes good solvent on addition of small amounts of camphor. G, Not solvent, but becomes good solvent on addition of large amounts of camphor. H, Can be used as diluent for E. I, Causes precipitation if used as diluent. Not solvent and does not become solvent on addition of camphor ([4, 7, 23, 26]).

H_2SO_4. <40%, A; 45%, B; 60%, D.

HNO_3. 14%, A; 25%, B; conc. D.

HCl. 13%, A; 25%, B after several days; 35%, B and D.

Acetic acid (CH_3COOH). Dilute, B; glacial, E.

Alkaline solutions. Weak at room temp., B; with increasing strength or temp., D.

Ketones, diacetone alcohol, wood spirit, methyl, ethyl, propyl, butyl or amyl acetate, nitrobenzene, E.

The lower aliphatic alcohols, C, F.

The ethers and the lower aromatic hydrocarbons, G, H.

$CHCl_3$, $C_2H_2Cl_4$, CCl_4, gasolene, turpentine, water, I.

Oils and fats, A, except for castor oil which has slight solvent action.

$SeOCl_2$, E.

Pyridine, D.

30. *Absorption of Water.*—([7]).

TESTS ON STANDARD TRANSPARENT MATERIAL

	Symbol	Thickness 0.015 in.	Thickness 0.860 in.
Net gain in weight of seasoned material, resulting from immersion in water,* %	A	1.3 to 2.1	1.6 to 2.3
Hours required to reach approximately maximum wt. and length		24	100 to 200
Net increase in length of seasoned material, resulting from immersion in water,* %	M	0.4 to 0.7	0.5 to 0.7
Loss of weight due to extraction of camphor in 2 months,† %	B	0.6 to 1.0	0.5 to 2.1
Total water absorbed by seasoned material,† %	A+B	2.3 to 2.6	2.8 to 3.2
Loss in weight of seasoned material in atmosphere dried by $CaCl_2$, ultimate, %	C	1.1 to 1.2	1.4 to 1.6
Hours required to reach approximately minimum wt. and length		100 to 200	700 to 1000
Decrease in length over $CaCl_2$, %	N	0.5	0.5 to 0.7
Maximum capacity for moisture, %	A+B+C	3.4 to 3.8	4 to 4.1
Change in length between extremes, %	M+N	1 to 1.2	1.2

* *I.e.*, net effect of absorption of water; extraction of camphor; replacement of alcohol by water (probably negligible).

† Neglecting replacement of alcohol by water.

31. *Molecular Complexity.*—"Films of celluloid have been made on water by evaporation of a dilute solution. The thinnest stable films are 10 Å thick, indicating that the molecular complex of celluloid is not over 10 Å in diameter" ([2]).

LITERATURE

(For a key to the periodicals see end of volume)

([1]) Addenbrooke, *121*, **66**: 629; 11. ([2]) Barton and Hunt, *68*, **114**: 861; 24. ([3]) U. S. Bureau of Standards, *O*. ([4]) Clement and Riviere, *La Cellulose*. Paris, 1920, p. 308–315. ([5]) Coker and Chakko, *62A*, **221**: 139; 20. ([6]) Curtis, *31A*, **11**: 359; 14. ([7]) du Pont Viscoloid Co., *O*. ([8]) Electrical Testing Laboratories, New York City, *O*. ([9]) The Fiberloid Corporation, *O*.

([10]) Filon and Jessup, *5*, **101**: 165; 22. ([11]) Heymans and Allis, *285*, **2**: 217; 23. ([12]) Heymans and Calingaert, *45*, **16**: 939; 24. ([13]) Martin, *248*, **6**: 323; 22. ([14]) Nishida, *296*, **4**: 287; 14. ([15]) Nishida, *45*, **8**: 1096; 16. ([16]) Ramspech, *8*, **74**: 722; 24. ([17]) Rossi, *71*, **16**: 206; 10. ([18]) Souder and Hidnert, *31A*, **15**: 408; 19. ([19]) Souder and Hidnert, U. S. Bureau of Standards, *O*.

([20]) Stifler, Columbia University, New York City, *O*. ([21]) Stokes and Weber, *32*, No. **98**; 17. ([22]) Tesche, *97*, **5**: 233; 24. ([23]) Ullmann, *B61*, **III**: 303; 15. ([24]) Weber, *31*, No. **192**; 12. ([25]) Will, *92*, **19**: 1382; 06. ([26]) Worden, *Nitrocellulose Industry*, I, Chap. IV (New York, Van Nostrand, 1911). *Technology of Cellulose Esters*, I, 2655–2759 (New York, Van Nostrand, 1921). ([27]) Dickinson and Van Dusen, *382*, **3**: 5: 16.

B. PHENOL RESINS AND THEIR PRODUCTS

("Bakelite," "Redmanol," "Condensite," Etc.)

L. V. REDMAN

Commercial Phenol Resins are phenol-formaldehyde condensation products, prepared under conditions that produce a resin capable of becoming hard, strong, insoluble and infusible with application of heat and pressure. Phenol Resin Products include: (1) Pure Resin; (2) Molded Products (employing as fillers wood flour, asbestos or other fibrous materials); and (3) Laminated

Products (prepared from paper or cloth which has been previously impregnated with the uncured resin).

The information given below is based upon data from (1, 2).

TYPE OF MATERIAL

Type	Molded, and filled with			Laminated and filled with			Pure resin
	Wood flour	Asbestos	Mica	Paper	Canvas	Cloth	
Symbol	M_W	M_A	M_M	L_P	L_C	L_{Cl}	P

Tensile Strength.—One-half inch figure-8 shaped test pieces for M and P materials (A. S. T. M. [D-48-24]). For L materials, values are parallel to laminations; *v.* (3) for shape of test piece.

Tensile strength = $A \times 10^3$ lb. in.$^{-2}$ = $A' \times 10^7$ dyne cm^{-2}.

Type	M_M, M_W and M_A	L_P	L_C	P
A.......	3.5– 6.0	8.7– 25	8.5–12	5–11
A'......	24 –40	60 –175	62 –80	35–75

Compressive Strength.—Inch-cube test-piece. (A. S. T. M. [D-48-24].) Compressive strength = $A \times 10^3$ lb. in.$^{-2}$ = $A' \times 10^7$ dyne cm^{-2}; at 20° unless otherwise noted; parallel or perpendicular to laminations as indicated.

Type	M_W	M_W, 100°	M_A	$L_P \parallel$	$L_C \parallel$	$L_C \perp$	P
A...	25– 36	12	18– 36	20– 45	20– 25	35– 47	26– 33
A'..	175–250	80	125–250	140–275	140–175	245–330	180–230

Modulus of Elasticity in Tension, Young's Modulus.—M = $1.5\text{–}2.5 \times 10^6$ lb. in.$^{-2}$ = $1.1\text{–}1.75 \times 10^{11}$ dyne cm^{-2} for the L_P material parallel to laminations; *v.* (3) for sample used.

Modulus of Elasticity in Bending.—Samples 12 in. long by 1 in. wide, with 10 in. span. M = load × span^3 ÷ 4 × width × thickness^3 × deflection at center = $1.1\text{–}2.1 \times 10^6$ lb. in.$^{-2}$ = $75\text{-}175 \times 10^9$ dyne cm^{-2} for the L_P material ⊥ to laminations.

Modulus of Rupture.—Samples 12 in. by 1 in. by 0.25 in.; 10 in. span. M = 3 × load × span ÷ 2 × width × thickness^2 =, for L_P material, 15 000–30 000, and for P material, 12 500 –20 000 lb. in.$^{-2}$ = for L_P, $1.05\text{–}2.10 \times 10^9$ and for P, $0.85\text{–}1.40 \times 10^9$ dyne cm^{-2}.

Impact Behavior.—(*a*) Olsen impact machine. Test piece 2½ in. × 1 in. × ½ in. with edges and corners rounded, 2 in. span. Drop increments of ½ in. between blows, from zero up to the breaking point. The values given below are the sums of the corresponding mass-height products.

Type		M_W	M_A	L_P	$L_C \perp$	P
Σ mh	lb. in.	500–1200	200–540	400–2000	3500–5300	500–1750
	kg cm	575–1380	230–620	460–2300	4000–6000	575–2000

(*b*) Pendulum method. Energy of blow to break a ½ in. square sample. L_P, ∥ 0.3–1.5 lb. ft.; 0.04–0.20 kg m; L_C, ∥ 2–3 lb. ft.; 0.25–0.40 kg m.

Bulk Density and Hardness.—Brinell test by application of 500 kg wt. for 30 sec. Scleroscope test with hard hammer.

Type		M_W	M_A	L_P	L_C	P
d, g cm^{-3}		1.33–1.40	1.78–2.00	1.32–1.40	1.36–1.40	1.20–1.29
Hardness	Brin...	30–38	38–42	35–45	33–38	30–45
	Scler...	78–92	75–95	84–94	60–67	75–110

Water Absorption.—Per cent gain in weight of sample (5 × 10 × 1¼ cm) after 24 hr immersion in water at 20°.

Type	M_W	M_A	L_P	L_{Cl}	P
Per cent gain.....	0.05–0.20	0.05–0.10	0.20–1.0	0.20–2.0	0.05–0.07

Softening Point Under Load.—A. S. T. M. method [D-17-T-1919]. M_W, 125–130; M_A, 130–150; L_P, 125–150; P, 75–100; deg. C. Do not flow under pressure of screw heads and similar forces at ordinary temperatures.

Thermal Expansion and Specific Heat.—Mean coefficient of linear expansion = $A \times 10^{-6}$ per °C between 20 and 70°. Specific heat, c_1 in joules g^{-1} per °C, c_2 in cal g^{-1} per °C or BTU lb.$^{-1}$ per °F.

Type		M_W	M_A	L_P	L_C	P
A..........		25–45	20–45	20–30	20–30	50–110
Sp. ht.	c_1, joules....	1.2–1.5	1.5–1.7	1.2–1.7		1.4–1.5
	c_2, cal or BTU.....	0.30–0.36	0.35–0.40	0.30–0.40		0.33–0.37

Electrical Resistivity.—At 20°C and 50% atmospheric humidity the total resistivity (in ohm) is of the order of 10^{10}–10^{11} for most types, that for the M_A material being somewhat lower, 10^8–10^9, and that for the pure resin sometimes higher, 10^{10}–10^{12}. The surface resistivity for L_P (in 10^9 ohm) is 10–90 000 for 24%, 0.9–660 for 50% and 0.1–15 for 84% relative humidity. Exposure to light, especially ultra-violet, decreases surface resistivity.

Dielectric Constant (ϵ) *and Power Factor.*—At radio frequencies. Phase difference = power factor (P. F.) × 0.57.

Type	M_W	M_M	L_P	L_{Cl}	P
ϵ.........	4.5–7.5	4–5	4.5–6.0	4.5–6.0	4.5–7.0
P. F., %..	1.5–7	0.5–1.5	1.5–5	2–7	0.2–3

Dielectric Strength.—A. S. T. M. low frequency test. L and P materials in $\frac{1}{32}$ in. sheets.

Type	M_W	M_A	L_P	L_C	P
Volts mil^{-1}..........	250–700	150–500	750–1300	250–500	250–700
Kilovolts cm^{-1}......	100–280	60–200	300– 500	100–200	100–280

Flash-over Voltage.—Between two 2 cm skirted brass studs 2 cm apart. Radio frequencies, L_P, 18–28; L_C, 18–25 kilovolts.

Optical Properties.—For the pure resins, n_D^{20} = 1.62–1.70. Quite transparent in the infra-red. Darkening occurs on long exposure to sunlight.

Miscellaneous Effects.—Exposure to (1) steam, does not affect mechanical properties but increases water absorption; (2) weak acids, no effect; (3) strong acids, charring of the organic fillers; (4) strong oxidizing acids, disintegration of the resin; (5) mild alkalis, softening; (6) strong alkalis, disintegration; (7) organic solvents, no effect; (8) aging, no effect.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bakelite Corporation, Research Lab., *O.* (2) Dellinger and Preston, *31*, No. **316**; 22. (3) Dellinger and Preston, *32*, No. **471**; 23. (4) A. S. T. M., American Society for Testing Materials.

C. COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS[1]

Hard rubber is composed of crude rubber, sulfur, and usually some mineral filling compound. The relatively high cost of crude rubber had induced some makers of hard rubber to use reclaimed rubber or else load the new rubber with a high percentage of mineral filler. The lack of a proper understanding of this fact between the maker and the user has often resulted in unjust censure of hard rubber as an insulator. The better grades of hard rubber are made of new rubber containing no mineral filler

[1] Dellinger and Preston, *32*, **316**: 619; 22.

and are free from excess sulfur. With these points in mind it is evident that the values assigned to a particular property or the effect of a certain test must necessarily be broad. Neither the best nor the poorest grade of hard rubber is considered in the data and opinions given in the following table.

Vulcanized fiber is made of parchmentized paper. For the better grades of fiber, rag base paper is used. The paper is run slowly through a warm concentrated solution of sulfuric acid or zinc chloride, the one solution being used in making fiber sheets one-eighth inch thick or less, the other solution being used for thicknesses greater than one-eighth inch. The purpose of the acid or zinc chloride is to soften the walls of the cellulose (cotton) fibers, so that when several sheets of treated paper are pressed together the fibers tend to mat and cohere. The treated paper is wound on a drum until the cylindrical tube of the desired thickness is obtained, the cylindrical tube being then cut so as to form a sheet whose width is equal to the width of the paper and whose length is equal to the circumference of the drum. The composite sheet of treated paper is then soaked in water to remove the acid or zinc chloride, dried, and pressed. The term "vulcanized" is somewhat misleading. Fiber does not depend upon heat and pressure to cure it as does hard rubber.

Vulcanized fiber varies much in both mechanical and electrical properties. The properties depend somewhat on the quality of rags used, the amount of residual sulfuric acid or zinc chloride, and upon the density of the finished product. Since the various processes of fiber making are difficult to control, the following statements relative to fiber must be taken as general and the recorded numerical data as average data.

The several makes and many grades of *laminated phenolic insulating material* are discussed quite fully in the paper. Any numerical value or statement given in the following summary table is an approximation.

The *molded phenolic insulating materials* are subject to as many variations as hard rubber. There is probably not as much variation in the phenolic resin binder in the molded phenolic materials as there is in the crude or reclaimed rubber binder of hard rubber. There are many other chances for variation in the press pressure and temperature, length of curing in the presses, and kind and quality of filler. Some of the fillers used are wood flour, pulverized mica, and asbestos. The kind and amount of filler will affect both the mechanical and electrical properties. All these possible variations make the data only approximate and require rather general statements in the summary table.

Most of the numerical data given in the table below are from tests made at the Bureau of Standards. The statements concerning the effects of various things on the different insulating materials are based on the experience of various members of the Bureau of Standards staff and upon the experience of the manufacturers of these materials. The manufacturers' experience on hard rubber and vulcanized fiber extends over many years, while the experience on the phenolic insulating materials is much more limited.

While it is possible to make up insulating materials which would give results different from those recorded for any particular property, yet it is believed that this table gives information in a condensed form which will serve to show some of the limitations as well as some of the possibilities of these various materials as now obtainable commercially.

Comparison of Properties of Hard Rubber, Vulcanized Fiber, Laminated and Molded Phenolic Insulating Materials

Properties	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Surface resistivity at 50% relative humidity, ohm	10^{12} to $>10^{15}$		10^{11}	10^{11}
Phase differences (ψ) at radio frequencies, deg	0.5*	3.0†	1.5 to 4.0	1.5 to 4.0
Dielectric constant (ϵ) at radio frequencies	3.0*	5.0†	4.5 to 6.0	5.0 to 7.5
Dielectric strength, volt/mm	10 000 to 38 000‡§	9 000 to 16 000‡§	27 000 to 45 000‡§	9 000 to 40 000‡§
Tensile strength, lb./in.^{2}	3 500 to 6 500	9 000 to 20 000	10 000 to 25 000	3 500 to 7 000
Water absorbed in 24 hr, percentage by weight	0.02	26 to 45‖	0.2 to 1.0¶	0.05 to 0.2**
Density, g/cm^3	1.12 to 1.40††	1.3 to 1.5	1.3 to 1.4	1.3 to 1.4
Thermal expansivity (at 20 to 60°C)	60 to 80 $\times 10^{-6}$	27 $\times 10^{-6}$	20 to 30 $\times 10^{-6}$	25 to 45 $\times 10^{-6}$
Effects of various agents				
Age	Deteriorates slowly, but if properly vulcanized and protected from the light it is not affected	Improves in quality by seasoning‡‡	Improves§§	No depreciation in physical or chemical properties; slight increase in hardness§§
Heat	At 65.5°C (150°F) pure hard rubber softens perceptibly; at 100°C (212°F) it is so soft it may be bent easily; at 115.5°C (240°F) it becomes leathery and may readily be cut with a knife; melts at 200°C (392°F)‡	Will not melt under any circumstances; not readily inflammable; at very high temperature chars and becomes brittle; active combustion begins at about 343°C (650°F)	Not readily inflammable; will withstand continuously a temperature of 149°C (300°F); heat tends to complete the reaction and volatile substances are driven off. Hence, when cooled it shrinks considerably and may split; shrinks and loses in weight above 60°C‖‖	See statement for laminated materials for cellulose-filled molded materials. Asbestos-filled and mica-filled materials are much more resistant to heat¶¶

COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS.—(*Continued*)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Sunlight	Discolors and disintegrates after a few months; the sulfur of the hard rubber is oxidized, forming the equivalent of sulfuric acid; this may take up ammonia from the air or may attack the filling materials and form various sulfates upon the surface; the surface resistivity is greatly reduced***	No effect‡	No visible effect†††	After two and one-half years some materials show a slight change, such as discoloration or very fine cracks; other materials show no such change‡†††
Ultra-violet light for 20 hr	Discolors and disintegrates; the action is as pronounced for a few hours' exposure to ultra-violet light as for many months' exposure to sunlight; the surface resistivity is greatly reduced***	No data	Appreciable lowering of surface resistivity	Appreciable lowering of surface resistivity***
Moist air	Hard-rubber compounds excepting those containing organic substances other than rubber are practically moisture proof	Absorbs water freely, but without permanent injury; while saturated it becomes soft and flexible and swells; warps and twists upon drying	Absorbs slight amount of water, reducing dielectric properties‡‡‡	Absorbs slight amount of water, reducing dielectric properties
Steam	The only effect is that due to the high temperature	Same as above, except absorption is more rapid	Best grades not affected beyond slight absorption of moisture; after a few days in steam the cheaper grades will swell appreciably and split; superheated steam tends to warp and blister all grades of the material	Absorbs a slight amount of moisture; if steam is superheated, the high temperature will cause decomposition of cellulose-filled materials. The mineral-filled materials are much more resistant to heat
Solvents:				
Acetone	Attacks, dissolving oils and free sulfur‡	No permanent effect‡	No effect‡§§§	No effect‡§§§
Alcohol	Attacks to a slight degree‡	No permanent effect‡	No effect‡§§§	No effect‡§§§
Ammonia	No effect‡	No permanent effect‡	Strong solutions may cause material to swell‡	No effect other than slight absorption of moisture‡
Aniline	Softens at ordinary temperature‡	Not known	Probably no effect‡	Probably no effect‡
Benzene	Softens at ordinary temperature‡	No permanent effect‡	Probably no effect‡§§§	Probably no effect‡§§§
Carbon bisulfide	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	Probably no effect‡§§§	Probably no effect‡§§§
Ether	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	No effect‡	Probably no effect‡§§§
Naphtha	Softens and swells to slight extent‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§
Oil of turpentine	Dissolves in boiling oil‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§

Comparison of Properties of Hard Rubber, Vulcanized Fiber, Laminated and Molded Phenolic Insulating Materials.—(*Continued*)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Oil:				
Mineral	Slight softening‡	Slight absorption‡	Practically impervious‡	Practically impervious‡
Organic	Unaffected‡	Slight absorption‡	Practically impervious‡	Practically impervious‡
Weak acids	Unaffected‡	Swells due to absorbed water; may be attacked after some time‡	Practically unaffected except for absorption of water‖‖‖	Practically unaffected¶¶¶
Weak caustic alkalis	Unaffected‡	Swells due to absorbed water; may be attacked after some time‡	Does not successfully resist the action of alkali unless very dilute	Does not successfully resist the action of alkali unless very dilute
Stronger acids (HNO_3, HCl, H_2SO_4)	Not attacked by concentrated hydrochloric, hydrofluoric, acetic acids; not attacked by sulfuric acid of less than 1.50 specific gravity or nitric acid of less than 1.12 specific gravity‡	Cellulose fiber attacked; soon decomposes	Decomposes; rapidity depends on specific gravity and temperature of acid	Cellulose-filled materials decompose; rapidity depends on specific gravity and temperature of acid. Molding materials made with acid-resistant fillers, such as mica, offer much greater resistance****
Stronger caustic alkalis	No effect	Cellulose fiber attacked; soon decomposes	Binder and filler decompose¶¶¶	Completely destroyed; speed of the reaction depends on the strength of the solution
Ozone	Oxidizes and soon ruins for electrical purposes	No effect‡	Not known	Not known
Metallic inserts	Rapidly deteriorated by contact with iron or copper, the metals themselves being corroded; the inserts should be coated with tin, paper, unvulcanized rubber, or other mutually protecting medium	No effect‡	No effect	No effect
Miscellaneous				
Machining qualities	Admits of a high polish; machines less accurately than would be supposed, due to great resiliency; the better the grade the more readily it is machined; quality may be judged roughly by color and texture, toughness, color, and grain of a shaving; has tendency to warp; can be molded but not accurately to size	Admits of a fine finish; may be sawed, punched, drilled, stamped, embossed, turned, planed, bent, tapped; tough, resists shock; can not be molded††††	Admits of a good polish; can be sawed, punched, drilled, stamped, turned, planed, knurled, embossed, milled, tapped either with or against the grain, though not as easily as hard rubber and vulcanized fiber; tough, resists shock; cannot be molded††††	Admits of a fine lasting polish; can be machined, cut, filed, sawed with difficulty; can be molded accurately to size; quite brittle
Cost (1922)	About $2 per pound in sheet form	50–80 cents per pound up to 1 inch in thickness; about $5 per pound for 2 inches in thickness	About $1 per pound	Cost varies with complexity of steel molds

* These values were obtained at frequencies between 750 000 and 75 000 cycles per second (400 to 4000 meters wave length), there being very little change throughout this range. The grade of the sample tested is unknown, so values differing somewhat from these might be expected on other samples using different quantities and kinds of filler.

† Values of ψ and K may be somewhat lower or much higher, depending on amount of moisture present in the fiber.

‡ Information obtained from sources other than the Bureau of Standards.

§ Values vary with the thickness of sample, kind of filler, shape of electrodes used, rate of increase of voltage, as well as atmospheric conditions under which tests are made.

‖ The Railway Signal Association specifications require an absorption when immersed in water at 70°F for 24 hours, not to exceed 45% by weight for one-eighth inch fiber, 30% for three-sixteenth inch fiber, and 26% for one-fourth inch fiber.

¶ Dependent upon nature of surface, surface area, and kind and amount of filler.

** Varies with polish of mold, press pressure, and temperature, length of curing, ratio of resin to filler, kind of filler, and size of sample.

†† The density depends on the amount of sulfur present and increases with the increase in amount of filler. Pure hard rubber ranges from 1.12 to 1.25. A fair commercial quality ranges from 1.25 to 1.40.

‡‡ This means seasoning or aging in a protected place, such as a storage house.

§§ These materials are of comparatively recent development, and hence no information has been gained covering very long periods. Theoretically, under certain conditions the chemical reactions would tend to continue, which would age and improve the material. One manufacturer claims a slight improvement in dielectric properties and a marked improvement in machining qualities when the aging takes place under ordinary atmospheric and temperature conditions. If the aging takes place in a moist atmosphere, the dielectric properties are subject to deterioration.

‖‖ *See* pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.

¶¶ When subjected to temperatures above 60°C (140°F) some of the volatile matter is driven off, resulting in the shrinking and loss in weight of the material. This can be carried out many times with the same result, the material becoming more brittle. Tests made on these materials show that they are very erratic in behavior and do not expand or contract in a uniform way. It seems altogether probable that a point would be reached after all volatile matters had been driven off, when further subjection to a moderate temperature and subsequent cooling would not result in further shrinkage. This has not been proved experimentally. High temperature will produce decomposition. Further information regarding these tests will be found in Scientific Paper of the Bureau of Standards No. 352. (*See also* pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.)

*** A further discussion of the tests at the Bureau of Standards may be found in Scientific Paper of the Bureau of Standards, No. 234.

††† *See* effect of ultra-violet light.

‡‡‡ *See* discussion on pages 599 and 600 of Technologic Paper, U. S. Bureau of Standards, No. 216.

§§§ Strong solvents affect the phenolic binder of the material to a limited extent unless the chemical reaction has been carried to the point where it is in the insoluble state. This condition would render the sheet material too brittle for general use. When water is present, the material will absorb it in various amounts.

‖‖‖ The effects vary with the materials, different molding mixtures, and acids. Nitric acid is harmful. In general weak acids will mar the surface and attack the edge of a sample soon after they come in contact with the sample, but there is little or no further change.

¶¶¶ *See* page 608 of Technologic Paper No. 216.

**** The action differs for various materials and grades. Some materials resist the action of a 30% solution of H_2SO_4 for several months and will withstand hydrochloric acid without any visible sign of attack. On other materials of this class sulfuric and nitric acids attack the surface of the sample and form a protective coating. This ruins the sample as far as further electrical use is concerned, but on removing the sample from the acid and cutting it open it is found that the acid has not penetrated more than one-sixteenth inch after several months' exposure to the acid.

†††† Thin sheets can be pressed to simple shapes when warm.

COMMERCIAL CARBONS FOR ELECTRICAL USES

N. K. Chaney

Manufactured carbon articles in the form of rods, plates, blocks, tubes, etc. in a wide variety of shapes are made by molding or extruding specially prepared mixtures of pulverized carbon "flours" with binding materials of tar or pitch, and subsequently carbonizing the binder at high temperatures. The resulting products always consist of a porous mass of carbon particles knit together by the residual carbon resulting from the decomposition of the binding materials. Because of the variations inherent in all manufacturing processes the physical properties of commercial carbons are subject to characteristic variations, the allowable range of which is determined by the service and cost requirements of the consumer. A high degree of precision in the individual determinations is therefore valueless, the typical range of variation being alone significant. Individual values where given must be regarded merely as representative.

Characteristic Range in Physical Properties of Typical Grades of Commercial Carbons (5)

	Resistance milliohm-cm	Density, g/cm³		Scleroscope hardness
		True*	Bulk	
Coke electrodes	3.5 –5.0	2.00–2.10	1.53–1.64	
Coal electrodes	3.3 –6.3	1.95–2.10	1.50–1.67	
Brushes:				
Electrographitic A	4.0 –5.0	2.03–2.07	1.50–1.60	49–61
Electrographitic B	0.8 –1.8	2.16–2.19	1.41–1.61	20–36
Artificial graphite	2.3 –3.8	2.08–2.10	1.45–1.60	30–45
Natural graphite	0.25–0.50	2.23–2.27	1.85–2.00	10–20
Arc light carbons	7.0 –8.0	1.85–1.90	1.30–1.40	70–80

* By immersion in kerosene.

Temperature Coefficient of Resistance (3)

t°C	% resistance		t°C	% resistance	
	Carbon	Graphite		Carbon	Graphite
25	100	100	2000	77.6	68.0
400		94	2200		69.0
800		81.5	2400	65.9	
1200	91.6	66.0	2800	50.9	
1600	87.0	65.0	3500	22.4	

Thermal Expansion

	Δt°C	$\frac{10^6 \Delta l}{l\,\Delta t}$	Lit.
Electrodes:			
Coal	220–1820	11.0	(5)
Coke	180–1920	7.2	(5)
Graphite	440–1720	10	(5)
Graphite		$0.55 + 0.0032t$	(2)
Arc carbon:			
Lampblack	25–1000	6.0	(5)
Coke		0.32	(4)
Coke		1.5	(4)
Coke		2.05	(4)
Coke		3.0	(4)

Mean Specific Heat, g-cal/g per °C (1)

Δt °C	Carbon	Graphite	Δt °C	Carbon	Graphite
26– 76	0.168	0.165	36– 902		0.324
26–282	.200	.195	47–1193		.350
26–538	.199	.234	48–1180	0.351	
30–752		.290	56–1450	.387	.390
40–892	.314				

Thermal Conductivity

K = g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$

10^2K	Range, °C	10^2K	Range, °C
Electrographitic brush A (5)		39	180– 220
2.9	20– 43	35	260– 340
Natural graphite brush A (5)		31	350– 450
3.9	20– 43	29	440– 560
Graphite electrode (3, 5)		27	500– 700
5.7	20– 43	0.019	2800–3200
50	90– 110		

Thermal Conductivity.—(*Continued*)

10^2K	Range, °C	10^2K	Range, °C
Coke electrode (3, 5)		1.7	200–340
0.79	20– 40	1.2	240–523
1.6	37–163	1.2	263–543
1.7	105–225	1.2	283–597
1.1	160–325	0.019	3000
1.6	170–330		

LITERATURE

(For a key to the periodicals see end of volume)

(1) Acheson Graphite Co., *O.* (2) Day and Sosman, *45*, **4**: 490; 12. (3) Hansen, *78*, **16**: 329; 09. (4) Muraoka, *8*, **13**: 307; 81. (5) National Carbon Company, *O.*

INDUSTRIAL ELECTRICAL INSULATORS

Contents	Matières	Inhaltsverzeichnis	Indice	Page

[1] Consult the desired property in the index of I. C. T.

[1] Consulter la propriété désirée dans l'index des I. C. T.

[1] Siehe die entsprechenden Eigenschaften im Index der I. C. T.

[1] Consultarne le proprietà nell'indice delle T. C. I.

Abbreviations

B. D.	Complete breakdown
B. T.	Burning temperature
D	Diameter
d	Specific gravity, room temperature, water = 1
E.	Engler viscometer; data given in Engler degrees
F. T.	Flash point
G	Spark gap = minimum distance between surfaces of electrodes
Max.	Maximum
P. D.	Potential difference between electrodes
P. F.	Power factor
P. Sp.	Preliminary sparking
S. T.	Solidifying temperature
S. U.	Saybolt Universal viscometer; data given are times of efflux, seconds
V	Viscometer value. For interconversion of E. and S. U. data, and for conversion of either to kinematic viscosity, *see* Vol. I, p. 33
% Δ	Per cent deviation from mean
ϵ	Dielectric constant
ρ	Volume resistivity

Abréviations

B. D.	Rupture diélectrique complète
B. T.	Température de combustion
D	Diamètre
d	Poids spécifique, à la température de la chambre, eau = 1
E.	Viscosimètre d'Engler; données en degrés Engler
F. T.	Point d'inflammabilité
G	Distance explosive = distance minimum entre les surfaces des électrodes
Max.	Maximum
P. D.	Différence de potentiel entre électrodes
P. F.	Facteur de puissance
P. Sp.	Lueur préliminaire
S. T.	Température de solidification
S. U.	Viscosimètre universel de Saybolt; les valeurs données sont les durées de l'écoulement en secondes
V	Constante du viscosimètre. Pour l'interconversion des valeurs de E. et S. U., et pour la conversion de ces deux valeurs en viscosité cinématique, voir Vol. I, p. 33
% Δ	Pourcentage d'écart de la moyenne
ϵ	Constante diélectrique
ρ	Résistivité

Abkürzungen

B. D.	Dielektrische Festigkeit
B. T.	Brenntemperatur
D	Durchmesser
d	Spezifisches Gewicht, Zimmertemperatur, Wasser = 1
E.	Engler Viskosimeter, Werte in Englergraden
F. T.	Entflammungspunkt
G	Funkenstrecke = minimal Entfernung der Oberflächen der Elektroden
Max.	Maximum
P. D.	Potentialdifferenz zwischen den Elektroden
P. F.	Kraftfaktor
P. Sp.	Glimmentladung
S. T.	Erstarrungstemperatur
S. U.	Saybolt Universalviskosimeter, die angegebenen Daten sind Ausflusszeiten in Sekunden
V	Viskosimeterwert. Für die gegenseitige Abmessung von E und S. U. Werte, für die Umrechnung auf die kinematische Viskosität siehe Vol. I, p. 33
% Δ	Prozentuelle Abweichung vom Mittel
ϵ	Dielektrizitätskonstante
ρ	Widerstand im Inneren

Abbreviazioni

B. D.	Interruzione continua
B. T.	Temperatura di combustione
D	Diametro
d	Peso specifico, temperatura ordinaria, acqua = 1
E.	Viscosimetro di Engler, valori in gradi Engler
F. T.	Punto di infiammabilità
G	Lunghezza di scintilla = distanza minima tra le superficie degli elettrodi
Max.	Massimo
P. D.	Differenza di potenziale tra gli elettrodi
P. F.	Fattore di potenza
P. Sp.	Preliminare scintillamento
S. T.	Temperatura di solidificazione
S. U.	Viscosimetro universale Saybolt; i valori riportati rappresentano tempi di efflusso in secondi
V	Valore viscosimetrico. Per la conversione dei valori E. in S. U. e viceversa, e per la conversione degli uni e degli altri in viscosità cinematica, vedi Vol. I, p. 33
% Δ	Deviazione percentuale della media
ϵ	Costante dielettrica
ρ	Resistività di volume

INSULATING OILS

J. B. Whitehead and J. H. Lampe

Only oils commonly used in industrial electrical apparatus are considered in this section. For data on other oils which might possibly meet industrial requirements, reference must be made to other sections of this volume. Among the following data are some for 7 distinct samples of domestic (U. S. A.) oil; these oils are here designated by the letters A to F, inclusive.

On n'utilise dans les appareils électriques que les huiles minérales de paraffine; on n'a considéré que de telles huiles dans cette section. Pour les données relatives á d'autres huiles qui peuvent présenter, éventuellement, une utilisation industrielle, il faut s'adresser á d'autres sections de ce volume. Parmi les données suivantes, il s'en trouve pour 7 échantillons distincts d'huiles indigènes (U. S. A.); ces huiles sont désignées par les lettres A à F, inclusivement.

Es werden nur Mineralöle paraffinischen Ursprunges in den elektrischen Apparaten benützt, nur solche sind deshalb Gegenstand des Abschnittes. Für Zahlenwerte weiterer Öle, welche vielleicht industrielle Beachtung verdienen, muss an anderer Stelle dieses Bandes nachgesehen werden. Unter den folgenden Werten sind 7 von heimischen (U. S. A.) Ölproben vorhanden. Diese Öle sind hier vom Buchstaben A bis einschliesslich F angeführt.

Solo gli olii minerali di paraffina sono adoperati negli apparecchi elettrici, e solo essi perciò sono qui presi in considerazione. Per le caratteristiche di altri olii che potrebbero eventualmente soddisfare alle richieste vedi altri capitoli di questo stesso volume.

Tra i valori che seguono sono riportati quelli di 7 campioni di olii degli S. U. A. Questi olii sono indicati con le lettere da A a F inclusa.

Table 1.—General Properties of Various Insulating Oils

For dielectric strength, *see* Table 2. Bracketed numbers indicate the range of variation; *e.g.*, first entry indicates that *d* varies from 0.846 to 0.915.

Unit of $\rho = 10^{12}$ ohm-cm; of ϵ = 1 cgse; of *P. F.* = 1%; of temperature = 1°C.

Oil / Prop.	U. S. A.			Germany*		France	Japan
	W. E. & M. (20)	G. E. (10)	Tobey (23)	Schendell (18)	Stern (22)	Crussard (4)	Hirobe (8)
d	0.846 0.915	0.83 0.93	0.845 0.870	0.85 0.92	0.85 0.95	0.85 0.92	0.827 0.861
V	50 100 S. U. 40°	40 120 S. U. 40°	40 110 S. U. 40°	8° 10° E. 20°	8° E. 20°	8° E. 20°	1.43° 2.96° E. 30°
ρ	13.2	20 150					
ϵ	2.5	2.15					
S. T.	− 2 −34	0 −40	−10 −15		−5	−1	
F. T.	140 170	130 190	130 190	160 170	160	160	125 152
B. T.			140 215	180 190		180	
P. F.	0.44	0.03 0.06					

* Heat conductivity of a German oil is given as 0.00031 cal/(cm deg sec) (24).

Table 2.—Dielectric Strength of Various Transformer Oils

Average effective breakdown voltage

Unit of voltage = 1000 effective (r. m. s.) volt; of *D* and *G* = 1 in. = 2.54 cm.

Diameter (*D*) Gap (*G*)	Sphere 0.5 0.15	Disk 0.5 0.15	Needle points 0.15	Disk point 0.15	Disk 1 0.1	Lit.
Tobey			18.0	16.5		(23)
Digby & Mills	11.5		17.5	11.0		(3)
N. E. L. A.	40.0	29.0				(12)
Peek	64.0	31.0	22.0			(13, 14)
Hirobe	92.0	62.0		15.0		(8)
Schroter	92.0					(19)
Everest	20.0	20.0	22.0	18.5		(5)
W. E. & M.	61.5	48.0			36.2	(1)
Vac. Oil Co.	51.7	37.1			24.0	(1)
B. S.	61.3	49.9			28.2	(1)

Table 3.—Dielectric Strength of Insulating Oil E (5, 25)

Breakdown voltage: Effective (r.m.s.) kilovolt

Units of D = 1 in.; of G = 0.001 in.; 1 in. = 2.54 cm.

G	Sphere, D = 0.5			Disk, D = 0.5			Needle points			Point, disk		
	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ
25	3.6	2.9	40							8.4	7.1	10
50	5.7	4.3	30	6.5	4.7	15	1.2	8.1	15	12.2	8.2	15
75				8.9	6.2	30						
100	13.2	7.6	40	14.5	7.4	40	17.8	13.5	10	16.0	11.8	8
150	19.5	11.1	30	19.1	11.1	40	22.1	16.3	8			
175										19.7	14.7	5
200	27.2	15.3	15	27.9	22.1	20	24.4	18.7	6			
250							26.7	20.4	8	23.3	17.4	6

Table 4.—Dielectric Strengths of Four U. S. A. Transformer Oils (1)

Parallel tests by Vacuum Oil Co. (Vac.), Westinghouse Electric and Manufacturing Co. (W), and National Bureau of Standards (B. S.). Most accurate data available. Each number is average of 15 observations; individual deviation from mean = 10%, the same in all cases.

Unit of D and G = 1 in. = 2.54 cm. V = 1 sec by S. U. at 0°C.

Electrodes	Gap G	Breakdown values, effective (r. m. s.) kilovolt, 60 cycles, 25°C							
		B. S.	Vac.	W	Mean	B. S.	Vac.	W	Mean
		A (d = 0.854, V = 55)				B (d = 0.867, V = 100)			
Disks D = 1	0.05	15.2	11.7	18.0	15.0	15.2	8.9	14.3	12.8
	0.10*	23.6	23.2	35.8	27.5	26.5	22.3	30.5	26.4
	0.15	33.6	32.9	39.3	35.3	36.3	32.2	42.8	37.1
	0.20	40.6	39.1	53.8	44.5	42.8	37.6	55.7	45.4
Disks D = 0.5	0.05	21.2	15.3	22.2	19.6	21.5	13.2	20.9	18.5
	0.10	37.9	29.4	38.9	35.4	37.1	24.8	38.7	33.5
	0.15	48.7	38.9	47.5	45.0	47.9	33.4	42.8	41.4
	0.20	49.3	45.2	51.0	48.5	49.8	46.1	54.9	50.3
Spheres D = 0.5	0.05	23.6	23.6	29.5	25.6	22.6	20.7	25.3	22.9
	0.10	44.2	45.5	51.1	46.9	38.5	35.2	48.6	40.8
	0.15	61.1		67.1	64.1	56.0	51.1	60.6	55.9
	0.20	68.9			68.9	70.5			70.5
		C (d = 0.829, V = 34)				D (d = 0.860, V = 74)			
Disks D = 1	0.05	16.5	8.8	18.5	14.6	16.8	11.0	17.8	15.2
	0.10*	33.5	25.9	40.7	33.4	29.1	24.6	37.8	30.5
	0.15	39.5	32.5	53.7	42.0	38.5	30.9	48.7	39.4
	0.20	50.8	39.8	64.8	51.8	41.2	37.9	59.8	46.3
Disks D = 0.5	0.05	27.1	20.0	24.9	24.0	25.8	14.0	19.4	19.7
	0.10	48.4	34.6	42.9	42.0	41.0	26.9	40.7	36.2
	0.15	48.8	42.3	57.9	49.7	54.3	33.7	47.0	45.0
	0.20	60.0	50.6	67.4	59.3	55.5	42.5	52.8	50.3
Spheres D = 0.5	0.05	33.4	26.3	32.9	30.8	26.2	22.5	30.0	26.2
	0.10	49.1	50.2	55.3	51.5	50.1	43.8	56.4	50.1
	0.15	67.1			67.1	61.1	52.4	56.7	56.7
	0.20					72.5			72.5

* This is the standard gap recommended by American Society for Testing Materials (1)—1 in. flat disks with square shoulders, spaced 0.1 in. apart. For this gap, the B. D. value for transformer oils should lie in the range 26.4 to 33.4 kilovolt.

Table 5.—Relative Breakdown Voltages for Three Commercial Test Gaps (1)

(Voltage, gap E_1)/(voltage, gap E_2)

Unit of D and G = 1 in. = 2.54 cm.

E_2 \ E_1	A	B	C
A	1.00	1.80	2.05
B	0.55	1.00	1.20
C	0.50	0.85	1.00
	Disk	Disk	Sphere
D	1	0.5	0.5
G	0.1	0.2	0.15

Table 6.—Error in the Average of n Tests of Dielectric Strength of an Oil

Based on 3000 tests (6, 7)

Unit of error = 1%.

n	Error	Sphere long*	Sphere short*	Point, sphere
1	Av.	7.8	7.8	8.4
1	Max.	48.5	34.1	44.8
3	Av.	5.2	4.9	4.9
3	Max.	22.4	19.7	19.1
6	Av.	2.7	3.5	4.1
6	Max.	17.5	15.0	14.3

* Average: Long = 27 mm; short = 2 mm.

Table 7.—Sparkover Voltage between Concentric Cylinders (14)

For $\frac{R}{r} > 3.5$ corona appears in transformer oils before sparkover occurs; for $\frac{R}{r} < 3.5$, the sparkover and corona voltages are the same and obey the relation: $g = 36\left(1 + \frac{1.2}{\sqrt{r}}\right)$. g = maximum voltage gradient at surface of electrode, in kilovolt/cm; R, r = radius of outer, inner, cylinder in cm; g_o, g_c = g_x observed, g computed. The * denotes where R/r becomes less than 3.5.

Unit of r = 1 cm; of P. D. = 1000 volt; of g = 1000 volt/cm (R = 3.81 cm).

r	P. D., max.	g_o	g_c
0.238	84.0	127.7	123.8
0.317	85.5	108.1	112.7
0.635	98.3	86.3	90.3
0.794	106.1	85.5	84.6
0.952	103.2	78.1	80.2
1.111*	108.5	79.4	76.9
1.270	107.5	77.0	74.3
1.587	104.3	75.1	70.4
1.905	93.7	70.7	67.2
2.540	64.3	62.4	63.1

Table 8.—Influence of Moisture on Dielectric Strength

Kilovolt (kv) for breakdown; disks, D = 0.5 in., G = 0.2 in.; temp. 25°C; U. S. A. Oil F (13, 14)

Water, volume in 10 000	0	0.5	1.0	2.0	5.0	10.0
Kv, 60 cycles, maximum	62.3	33.5	33.4	31.7	27.3	25.4
Kv, constant voltage	61.5	34.7	34.3	30.2	24.7	23.0

Ryan (17), Tobey (23), Peek (13, 14, 15), and others (11, 16, 2) show that moisture in very small quantities decreases the dielectric strength of insulating oil.

Hirobe (8), McLaughlin (9), Stern (22), Spath (21), and Schroter (19) agree experimentally that moisture has little effect on the dielectric strength of the purest oils. The potent causes of low dielectric strength are fibers and dust particles in the oil.

Their effect is increased by the presence of moisture (*cf.* Table 9). For methods and effect of cleaning electrodes, *see* ([8]).

TABLE 9.—DIELECTRIC STRENGTH: EFFECT OF CLEANING AND DRYING THE OIL ([19])

F = effective field strength at which breakdown occurs
Unit of F = 1000 volt/cm; of $\%\Delta = 1\%$.

Condition of oil*	F	$\%\Delta$
As delivered	48.5	75
Filtered through 4 mm clay wall	115.0	50
Centrifuged	124.0	30
Filtered through ordinary filter paper	163.0	35
After prolonged drying by heat	184.0	40
Prolonged drying by heat and filtered once through celloid filter	232.0	8
As in preceding, but filtered twice	332.0	7

* Each line of the table is complete in itself; tests were not successive.

TABLE 10.—RESISTIVITY (R) AND DIELECTRIC STRENGTH (S) OF DRY OIL: VARIATION WITH TEMPERATURE ([23])

R is expressed in terms of the resistance between disks, D = 4 in., G = 0.44 in.; S in terms of the effective breakdown P. D. between spheres, D = 0.5 in., G = 0.15 in. Approximately $S = S_{25} - 0.13\ (t - 25°)$ kilovolt ([1]); t = temperature, °C; S_{25} = value of S at 25°C.

Unit of S = 1000 volt; of $R = 10^6$ ohm; of t = 1°C.

Temperature (t)	30	40	50	60	70	80	90°C
Strength (S)	33	35	36	37	38	39	41
Resistivity (R)			1225	960	570	360	250

LITERATURE

(For a key to the periodicals see end of volume)

([1]) Silsbee, *66*, **21**: 397; 21. ([2]) Armstrong, *107*, **62**: 1322; 13. ([3]) Digby and Mills, *46*, **28**: 769; 09. ([4]) Crussard, *106*, **13**: 443; 23. ([5]) Everest, *121*, **87**: 702; 21. ([6]) Hayden and Eddy, *129*, **41**: 102; 22. ([7]) Hayden and Eddy, *129*, **41**: 394; 22. ([8]) Hirobe, *Elect. Technical Laboratory Report*, No. **25**: Sect. 3 (Japan). ([9]) McLaughlin, *121*, **86**: 325; 21.

([10]) Moody, W. S., General Electric Co., Schenectady, New York, *O.* ([11]) Moody and Faccioli, *129*, **28**: 769; 09. ([12]) National Electric Light Association, *Bulletin*, June, 1910. ([13]) Peek, *129*, **35 II**: 783; 16. ([14]) Peek, *120*, **18**: 821; 15. ([15]) Peek, *Dielectric Phenomena in High Voltage Engineering*, Chap. IV. New York, McGraw-Hill Book Company, Inc., 1915. ([16]) Rodman, *114*, **20**: 51; 23. ([17]) Ryan, *129*, **30**: 1; 11. ([18]) Schendell, *101*, **37**: 242; 18. ([19]) Schroter, *125*, **12**: 67; 23.

([20]) Skinner, C. E., Westinghouse Electric and Manufacturing Co., East Pittsburgh, *O.* ([21]) Spath, *125*, **12**: 331; 23. ([22]) Stern, *101*, **48**: 140; 22. ([23]) Tobey, *129*, **29 II**: 1189; 10. ([24]) Tesche, *97*, **5**: 233; 24. ([25]) Wedmore, *121*, **87**: 702; 21.

INSULATING SOLIDS

F. MALCOLM FARMER

Because of inherent variations in composition and physical condition of both manufactured and natural products, no single value can be assigned to any of the various properties of solid electrical insulators. Furthermore, the value obtained in the measurement of many electrical properties depends upon the method employed and the conditions under which the test was made. For example, in determinations of either the volume or the surface resistivity, the result will depend upon the voltage employed, the duration of its application, temperature, humidity, etc. No standard procedure has yet been established for determining the various quantities. The available data have been obtained under a great variety of conditions and with many different procedures (which, in most cases, are not fully stated) so that the selection of values for these tables has been a matter of judgment, the aim being to select those values which it is believed are most typical and, consequently, the most reliable for general application. Some of the principal sources from which data have been obtained are named on p. 311. Discussions of some of these variable factors will be found in ([1, 3, 9]); for bibliographies, *see* ([2, 18, 19]).

Par suite des variations inhérentes à la composition et aux conditions physiques des produits manufacturés et naturels, il n'est possible d'assigner une valeur unique à aucune des propriétés variées des isolants électriques solides. De plus, les valeurs obtenues par les mesures de plusieurs propriétés électriques dépendent de la méthode employée et des conditions dans lesquelles l'essai a été effectué. Par exemple, dans les déterminations de la résistivité du volume et de la résistivité superficielle, le résultat dépend du voltage employé, de la durée de l'application, de la température, de l'humidité, etc. Aucune procédure type n'a encore été établie pour déterminer les quantités variées. Les données disponibles ont été obtenues suivant une grande variété de conditions et avec des procédures différentes (qui, dans la plupart des cas, ne sont pas complètement spécifiées); de sorte que la sélection des valeurs pour ces tables a été une question de jugement, l'objectif étant de choisir celles des valeurs qui étaient présumées les plus typiques et par conséquent les plus dignes de confiance pour l'application générale. Quelques unes des sources principales dont ont été tirées les valeurs sont indiquées à la page 311. On trouvera les discussions relatives à quelques uns des facteurs variables à ([1, 3, 9]); en ce qui concerne la bibliographie, *voir* ([2, 18, 19]).

Entsprechend der eigenartigen Änderung in der Zusammensetzung und des physikalischen Zustandes der festen Isolatoren, kann man sowohl den künstlichen als auch den natürlichen Produkten keinen einzelnen Wert ihrgend welcher der verschiedenen Eigenschaften zu ordnen. Es hängt ferner der gemessene Wert vieler elektrischer Eigenschaften von der angewandten Methode und den Bedingungen unter welchen die Probe ausgeführt worden ist, ab. Z. B. bei der Bestimmung des Oberflächen Widerstandes wird das Ergebnis von der angewandten Volt-Zahl, der Dauer der Einwirkung, der Temperatur, der Feuchtigkeit u. s. w. abhängen. Bis jetzt ist keine diesbezügliche Standardmethode zur Messung der verschiedenen Grössen aufgestellt. Die erreichbaren Daten sind unter den verschiedenen Bedingungen und sehr verschiedenen Prüfungsvorgängen (die in vielen Fällen auch nicht ganz angegeben sind) erhalten. Es ist deshalb diese Auswahl nach besonderem Urteil gemacht worden, mit dem Ziel im Auge, diejenigen Werte herauszugreifen, die man als die typischesten ansieht und demzufolge allgemein am zuverlässlichsten sein werden. Einige der hauptsächlichsten Quellen aus denen die Werte geschöpft wurden sind Seite 311 angegeben. Zur Diskussion einiger der veränderlichen Faktoren, ([1, 3, 9]), Literatur dazu, *siehe* ([2, 18, 19]).

A causa di alterazioni nella composizione e nello stato fisico sia dei prodotti artificiali che naturali, non si può assegnare un valore determinato alle varie proprietà degli isolanti elettrici solidi. Inoltre, il valore ottenuto nella misura di molte proprietà elettriche dipende dal metodo impiegato e dalle condizioni nelle quali la prova è stata fatta. Per espempio, quando si determina la resistività di volume o di superficie, il risultato dipende dal voltaggio adoperato, dalla durata di applicazione, dalla temperatura, dalla umidità, ecc. Non è stata ancora stabilita una procedura uniforme per determinare le varie grandezze.

I dati disponibili sono stati ottenuti in condizioni molto diverse e con metodi differenti (il più delle volte neppure completamente indicati); per modo che la scelta dei valori per queste tabelle è stata fatta con un certo arbitrio e con lo scopo di raccogliere i valori ritenuti più tipici e quindi suscettibili di una più generale applicazione.

Alcune delle fonti principali dalle quali i dati sono stati tratti sono indicate a pag. 311. Per la discussione di alcuni dei fattori variabili si veda ([1, 3, 9]) e per le indicazioni bibliografiche si veda ([2, 18, 19]).

Manufacturers Mentioned in this Section

M1 Alberene Stone Company, New York, N. Y.
M2 Chicago Mica Company, Chicago, Ill.
M3 Continental Fibre Company, Newark, Del.
M4 Electrose Manufacturing Co., Brooklyn, N. Y.
M5 Garfield Manufacturing Co., Garfield, N. J.
M6 General Electric Co., Schenectady, N. Y.
M7 General Insulate Co., Brooklyn, N. Y.
M8 Hemming Manufacturing Co., Garfield, N. J.
M9 Irvington Varnish and Insulator Co., Irvington, N. J.
M10 Mica Insulator Co., Schenectady, N. Y.
M11 Minerallac Electric Co., Chicago, Ill.
M12 Mitchell-Rand Mfg. Co., New York, N. Y.
M13 National Vulcanized Fibre Co., Wilmington, Del.
M14 Spaulding Fibre Co., Inc., Tonawanda, N. Y.
M15 D. M. Stewart Manufacturing Co., Chattanooga, Tenn.
M16 Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

TABLE 1.—INDEX AND DESCRIPTION OF MATERIALS

Glass, *v.* p. 87, porcelain, *v.* p. 66, rubber and rubber products, *v.* p. 254, phenol condensation products, *v.* p. 296

I. Bituminous, Wax and Molded Materials

Index No.

1. **Ambrion.**—A molded product (German). Asbestos, impregnated with a pitch or rosin binder. Several grades—some fireproof, some limited to 80 to 100°C.
2. **Asphalt.**—Various grades known as bitumen, byerlite, elaterite, gilsonite, manjak, and mineral pitch. A black, natural product found in various parts of the world. Used extensively as base for insulating varnishes, for impregnating insulating materials, and (in Europe) for insulating wires and cables (instead of rubber). Hard at ordinary temperatures, plastic at 40–60°C, melts at 100–200°C, depending upon purity.
3. **Beeswax.**—The secreted substances of which the bee's honeycomb is constructed; yellow; agreeable odor and taste. Solid at ordinary temperatures, plastic when warm, melts at 62–64°C.
4. **Ceresin.**—A yellow or white wax made by purifying and bleaching ozokerite (*see* 10). Used extensively in manufacture of insulating compounds.
5. **Electrose.**—Trade name for a product manufactured and molded by M4; working temperature limit, about 90°C.
6. **Gummon.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Black, hard, dense, not easily drilled or sawed, can be highly polished, and will withstand 200°C indefinitely.
7. **Hemit.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Hard, dense, not easily drilled or sawed; withstands temperature of 600 to 800°C. Grade "B" is gray and hygroscopic; grade "A" is impregnated, making it black and more nearly waterproof.
8. **Insulate.**—Trade name for a mineral product manufactured and molded in desired shape by M7. Non-hygroscopic; maximum working temperature, 70°C.
9. **Minerallac.**—Trade name for asphaltic base insulating material manufactured by M11 in various grades for different applications (principally cable joints, cable terminals, etc.). Some grades semi-liquid, others semi-solid at 25°C. Moisture-proof.
10. **Ozokerite** (*See* Ceresin).—A natural, mineral wax material, usually associated with rock salt or gypsum; found throughout the world, but principally in Galicia. Is probably paraffin resulting from natural decomposition of petroleum. Natural color brown or black, but white when purified; melts at 110°C.
11. **Paraffin.**—Translucent, more or less colorless wax material obtained in the distillation of petroleum. Various commercial grades; melts at 45 to 80°C, depending upon grade; unaffected by ordinary acids and alkalies.

11(*a*). **Petrolatum.**—A neutral and purified residue derived by distillation of petroleum. Three forms—liquid, soft, and hard. The soft form is a grease similar to vaseline and is used extensively as an impregnating material for paper insulated cables; melts about 50–55°C; electrical properties vary greatly with the purity.

12. **Rosin.**—A variety of resin. Product of distillation of oil of turpentine from crude turpentine.
13. **Tegit.**—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M8. Uses limited to 200°C.

II. Fibrous Materials and Fiber Products

14. **Cellulak.**—Trade name for laminated paper insulation manufactured by M9. Processed under heat and pressure. Hard, tough, readily machined.
15. **Cellulose.**—A carbohydrate similar in chemical composition to starch. When pure, is amorphous and white; is basis of practically all fibrous insulating materials. Unsized, well bleached linen paper is practically pure cellulose.
16. **Conite.**—(*See* 18.) Trade name for a thin, hard, vulcanized fiber prepared by M3 with special care to insure its freedom from acid.
17. **Empire Cloth.**—Trade name of M10 for various varnished cloths having coatings of linseed-oil base (*see* 29).
18. **Fiber, Vulcanized.**—Also known as fiber, horn fiber, hard fiber, indurated fiber, leatheroid, etc. Made by treating layers of paper stock made from pure cotton cellulose (old cotton rags free from dirt, oil, and grease) with concentrated acids or zinc chloride. Compressed under great pressure to desired thickness; soaked and washed in water for long periods to remove acid or chloride; air dried, pressed in steam-heated presses and calendered to final thickness. Hard, tough, bone-like, hygroscopic, absorbs water readily, disintegrates with strong acids, unaffected by organic solvents and oils, becomes brittle at 80 to 100°C sustained temperature, readily machined, various colors. Manufactured by M3, M13, M14, and others.
19. **Fish Paper.**—Also known as tarpon paper, leather paper, leatheroid, and fiberoid. Prepared in similar manner to vulcanized fiber using cotton rag stock. Flexible; dark gray; thickness about 0.1 to 1.2 mm.
20. **Kobak Cloth.**—Trade name (M10) for black varnished cambric (*see* 28).
21. **Kraft Paper** (For cables).—Unsized paper made from wood pulp stock by sulfate process (21*a*). Hygroscopic. Used extensively in Europe in high tension power cables where it is impregnated with an insulating material (21*b*) after application to conductors.
22. **Manila Paper** (For cables) (*See* 26).—Unsized paper made from old manila rope (22*a*). Used extensively in America on high tension power cables where it is impregnated with an insulating material (22*b*) after application to conductors.
23. **Paraffined Paper.**—Bond paper coated or saturated with hot paraffin. Used extensively in low voltage electric condensers.
24. **Pressboard.**—Also known as fullerboard and presspan (in Europe). A high grade cardboard paper made from cotton rag and paper clipping stock. Hygroscopic.

25. Pressboard, Treated.—Pressboard dried (sometimes in vacuum) and varnished (25*a*) or boiled in mineral oil (25*b*) to make it moisture-proof and to increase dielectric strength.

26. Rope Paper (*See* 22).—Paper made from old rope stock (hemp and jute). Compressed but unsized. Hygroscopic.

27. Varnished Cloth (*See* 17, 20, 28, 29, 30, 31 and 33).—Also known as treated cloth. Thin cotton, linen, or silk cloth dried and coated with various thicknesses of various kinds of liquid insulating materials so applied and treated as to produce a smooth, sheet insulating material which is flexible, tough, and uniform in thickness. Great variety manufactured (some under trade names) by M6, M9, M10, M12, M16, and others.

28. Varnished Cambric, Black (*See* 27).—Coated with an asphaltic material and an oxidizing oil. Black, oil-proof, but not moisture-proof; is more flexible, and remains flexible longer, than the yellow cambric; is, also, more resistant to action of corona discharge (*i.e.*, ozone and nitric acid). Thickness, 0.1 to 0.4 mm.

29. Varnished Cambric, Yellow (*See* 27).—Also known as varnished muslin, oiled cambric and oiled muslin. Coated with linseed oil and a resin; filler is yellow and translucent; absorbs moisture, but is oil-proof. Thickness, 0.1 to 0.4 mm.

30. Varnished Duck or Canvas, Black.—Same as black varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.

31. Varnished Duck or Canvas, Yellow.—Same as yellow varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.

32. Varnished Paper.—Paper [cotton (bond), linen, and hemp (manila) stock papers, also fish paper] treated like varnished cloth. Treatment greatly increases resistance to moisture absorption and increases dielectric strength (*ca.* 25 %).

33. Varnished Silk.—Same as yellow varnished cambric except that base is silk. Thickness, 0.05 to 0.2 mm.

34. Woods, Hard.—Maple, hickory, cherry, ash, and yellow pine principally used. Dried (34*a*) and impregnated with oil (34*b*), paraffin (34*c*) or rosin, either by boiling until evolution of gas ceases or by impregnation under pressure after drying *in vacuo*.

III. Mineral Materials

35. Alberene (*See* soapstone, 47).—A fine grade of natural soapstone uniformly gray in color, free from metallic veins. Marketed by M1. Does not split or shale under intense local heating, such as electric arc. Stated to be capable of withstanding 1300 to 1600°C. Soft, easily machined, sawed, and drilled.

36. Asbestos Paper.—Soft, flexible sheet material made from fibrous asbestos with 15 to 20 % cotton. Very hygroscopic.

37. "Lava."—A form of talc (hydrated magnesium silicate), similar to pumice, which, while in its natural state, is formed or machined to desired shape and then baked at 1100°C, making it very hard. It is then not affected by any lower temperature; very porous, but dimensions not affected by absorption of water; slightly affected by HCl, but not by other ordinary acids and alkalis; very light yellow.

38. Lavite.—Trade name for patented product manufactured by M15. Similar to "lava." Compares with glass in hardness; unaffected by temperatures up to 1000°C, or by ordinary acids or alkalis; porous; very light yellow.

39. Marble.—Crystalline limestone which takes a high polish. Pure marble is white; colored marbles contain impurities, such as iron oxide. Much used for electrical switchboards where, because of porosity, it is frequently impregnated with insulating material to increase dielectric strength; often stained black (called marine finish) to prevent discoloration due to oil staining, etc.

40. Mica.—A laminated mineral composed of crystallized anhydrous silicate of aluminum and potash, or soda. Pure mica is transparent, but frequently colored by salts deposited between laminations. Laminations easily separated so that mica can be split down to 0.005 mm. In natural state it is not uniform in quality, is not flexible, and largest pieces are relatively small; hence it is reconstructed, by splitting into thin laminations and cementing together the small pieces, with suitable binders, to form continuous sheets of various thicknesses, which are marketed under trade names (*see* 41 to 45 inc.). Powdered and flaked mica is used in conjunction with suitable binders to make molded insulations (a substitute for hard rubber, etc.). Properties vary considerably with impurity content, and with sources from which obtained, the principal of which are India, Africa, Canada, and United States. The clear variety has highest dielectric strength.

41. Mica Cloth.—Reconstructed mica (*see* 40) with special binder and backed with cloth. Flexible (to various degrees); thickness, 0.1 to 3 mm.

42. Mica Bond.—Trade name for mica cloth, mica paper, and mica plate products manufactured by M2 (*see* 41, 43 and 44).

43. Mica Paper.—Reconstructed mica (*see* 40) with special binder and backed with Japanese paper. Flexible; thickness, 0.25 to 0.5 mm.

44. Mica Plate.—Reconstructed mica (*see* 40) with shellac binder. Not flexible; thickness, 0.25 to 3 mm.

45. Micanite.—Trade name for mica cloth, mica paper, and mica plate products manufactured by M10 (*see* 41, 43, 44).

46. Slate.—Natural rock of clay or mica composition with natural cleavage. Formed by geological processes involving high temperature and pressure. Principal components are silica and alumina with some iron oxides, lime, magnesia, potash, and soda. Slate for electrical purposes is principally the mica variety from Vermont (purple to green), Maine, and Pennsylvania; the last two are dark gray (called black slate). Is hygroscopic and contains relatively large amount of water of composition, hence thorough drying followed by oil treatment or coating with insulating varnish or enamel greatly improves insulating value. Easily machined; takes good polish.

47. Soapstone (*See* Alberene, 35).—A natural, soft stone; a variety of talc. (Also called steatite.) Slightly soapy or oily to touch. Easily machined, drilled, and sawed. Hygroscopic. Withstands temperatures of the order of 1500°C.

IV. Gum Materials

48. Amberite.—(Ambroid.) Compressed scrap amber (fossilized vegetable resin). Equal to native amber in volume resistivity, but surface must be kept clean for high surface resistivity.

49. Copal.—A resinous substance which, when dissolved in alcohol, oil of turpentine, or linseed oil, makes a colorless varnish. Very inflammable; brittle when cold.

50. Shellac.—A crude form of lac, a resinous gum exuded by an East Indian insect, also obtained from sap of certain trees. Shellac dissolved in alcohol is extensively used as an insulating varnish which on drying forms hard, protective coating. Brittle, brown, hygroscopic.

V. Miscellaneous Materials

51. Enamel.—A hard, smooth, and flexible coating baked on magnet wire as substitute for cotton and silk, or in addition thereto. Composition more or less a manufacturing secret,

but stated in some cases to be stearin pitch, cellulose acetate, or cellulose nitrate. Applied by running wire through thin bath and rapidly drying each coat by passing through hot oven. Occupies less space than cotton and silk, has greater thermal conductivity; moisture-proof and mineral oil-proof, but more or less soluble in vegetable oil, animal oil, alcohol, turpentine, and coal tar solvents; withstands 100°C indefinitely; breaks down electrically at 300°C.

52. Galalith.—German product manufactured from skim-milk heated with caustic soda and precipitated with acid. The precipitate, in sheet and plate form, is dried, saturated with formaldehyde, and again dried and pressed. Used as substitute for ivory. Translucent and yellowish white; readily shaped, after softening in hot water; rather hygroscopic.

53. Ivory.—Tusks of the elephant, walrus, etc. Hard and white.

TABLE 2.—ELECTRICAL PROPERTIES

Volume resistivity (*see* Vol. I, p. 41) = $R_v \times 10^n$. Surface resistivity (*see* Vol. I, p. 41) = $R_s \times 10^n$. Power factor = $\cos \varphi$. Temperature = 18 to 25°C except as indicated. Unit of: R_v = 1 ohm-cm; R_s = 1 ohm; frequency = 1 cycle/sec; dielectric constant = 1 cgse (essentially, air = 1); thickness = 1 mm.

Index No.	Material	Resistivity				Dielectric constant		Dielectric strength		Power factor	
		R_v	n	R_s	n	Frequency	Constant	Thickness	Kv/mm	Frequency	$\cos \varphi$
35	Alberene	(*See* Soapstone)									
48	Amberite (ambroid)	5	16	2	15		2.8*				
1	Ambrion	2	13					0.8	6		
36	Asbestos paper	2	5					1.0	4		
2	Asphalt						2.7	2.0 to 3.0	1 to 2		
3	Beeswax	5 to 20†	14	8	14§		1.85		10		
14	Cellulak							3.0	16		
15	Cellulose	1	9				3.9 to 7.5				
4	Ceresin	5	18	8	16						
16	Conite							0.12	15		
49	Copal							3.0	3		
5	Electrose	·1 to 15	14	1 to 1000	12			3.0	25		
51	Enamel	1	14					0.02	20 to 25		
18	Fiber, vulcanized	5 to 20	9	1	10	90 to 650‡	5.0 to 7.5	1.0	8 to 18	90 to 650‡	0.045
								3.0	5 to 12		
								6.0	4 to 9		
								12.0	3 to 6		
19	Fish paper							0.1 to 1.2	10 to 15		
52	Galalith	1	10	6	10				6 to 8.5		
6	Gummon	3	12	3	12				3		
7	Hemit	1	10	1	10				2		
8	Insulate (No. 2)	8	15	4	14			10	1.5 to 2		
53	Ivory	2	8	6	9						
21*a*	Kraft paper							0.15 to 0.2	4 to 6		
21*b*	Kraft paper					60	3.5	0.15 to 0.2	30 to 40	60	0.005
37	"Lava"								3 to 10		
38	Lavite	5 to 25	8	1	11				8 to 10		
22*a*	Manila paper					920 to 4600	2.0	0.15 to 0.2	3 to 5	920 to 4600	0.007 to 0.008
22*b*	Manila paper	2	9			60	3.5	0.15 to 0.2	20 to 30	60	0.005
34*b*	Maple, oiled							25	3.0		
34*c*	Maple, paraffined	3	10	8	11		4.1	15	4.5		
39	Marble	1 to 100	9	6	9	60	8.3	25	2 to 4	90 to 650	0.003 to 0.05
						90 to 650‡	9.5 to 11.5				
40	Mica	1 to 200	15	1 to 3000	10		4.5 to 7.5	0.05	80 to 200	800	0.001 to 0.07
								0.3	40 to 120		
								0.6	25 to 75		
41, 43	Mica, cloth and paper							0.1 to 3	40 to 15		
44	Mica plate							0.1 to 3	50 to 25		
9	Minerallac					60	2.7	0.5	40		
10	Ozokerite	5	14				2.2	0.6	45		
11	Paraffin	1 to 500	16	1†	16		1.9 to 2.3		15 to 50		
23	Paraffined paper								40 to 60		
11*a*	Petrolatum	2 to 10	12			60	2.2	2.5	20	60	0.005
24	Pressboard	1	9					0.2 to 3.0	12 to 5		
25*a*	Pressboard						2.9	0.5 to 3.0	15 to 10		
25*b*	Pressboard						4.5	0.5 to 3.0	30 to 20		
12	Rosin	5	16	7	14		2.5				
50	Shellac	1	16	7	13		2.7 to 3.7				
46	Slate	1	8	1	8		6.0 to 7.5	25	0.2 to 0.4	950	0.086
47	Soapstone	6	8					25	1.0		
13	Tegit	2	12	7	11				2		
28	Varnished cambric b							0.1 to 0.4	70 to 50		
29	Varnished cambric y						3.5 to 5.5	0.1 to 0.4	60 to 45		
30	Varnished canvas b							0.4 to 0.8	12 to 30		
31	Varnished canvas y							0.4 to 0.8	25 to 10		
32	Varnished paper								10 to 25		
33	Varnished silk							0.05 to 0.2	70 to 45		
34*a*	Woods, hard, dried	1 to 4000	10			90 to 650‡	3.0	25	0.4 to 0.6	90 to 650‡	0.025

* Amber.

† Has very large negative temperature coefficient, R_v at 30° being about 1/16 of that at 90°C.

‡ Kilocycles.

§ Fresh surface. Deteriorates rapidly.

TABLE 3.—MECHANICAL AND THERMAL PROPERTIES 18 TO 25°C

Unit of: density = 1 g/cm³; strength = 1 kg/cm² (for Nos. 21, 22, 28 to 33 = 1 kg per cm width); expansivity = 10^{-4} per °C; thermal conductivity = 1 milliwatt per (cm °C).

Index No.	Material	Density	Strength		Cubic expansivity	Thermal conductivity
			Tensile*	Compressive		
1	Ambrion	1.4 to 1.8	150	190		
36	Asbestos paper	3.2				2.5
2	Asphalt	1.04 to 1.40			5 to 7	
3	Beeswax	0.96				0.35
4	Ceresin	0.75				
16	Conite		550 to 1100			
18	Fiber, vulcanized	1.2 to 1.5	625 to 1050	1800 to 3200	0.27	
52	Galalith	1.3				
6	Gummon		40	40		
7	Hemit		140	110		
53	Ivory	1.9				
21a	Kraft paper	0.8	500 to 700†			
21b	Kraft paper		400 to 500†			
37	"Lava"	2.5 to 2.7		1400 to 2100	Negligible	8
38	Lavite	2.5 to 2.7	400 to 800‡	1400 to 2100		
22a	Manila paper	0.8	700†			1.2
22b	Manila paper		500†			1.7
39	Marble	2.5 to 2.8	100 to 200‡	600 to 1500	0.3 to 0.6	30
40	Mica	2.7 to 3.1				3.6
41, 43	Mica, cloth and paper					1.0 to 1.6
9	Minerallac	1.0			7	
11	Paraffin	0.87 to 0.94			3 to 6	2.6
25a	Pressboard					1.4
50	Shellac					2.5
46	Slate	2.7 to 2.9	550 to 700‡	700 to 1000	0.15 to 0.3	20.0
47	Soapstone	2.6 to 2.8		550		
13	Tegit		85	80		
28, 29	Varnished cambric		8 to 10§			2.5
30, 31	Varnished canvas		10 to 20§			
33	Varnished silk		2 to 3§			
34	Woods, hard, dried	0.6 to 0.9	500 to 1000	250 to 550	0.1 to 2.0	1.5 to 2.5

* For Nos. 38, 39, 46 data are for transverse strength, as noted.
† In machine direction (*i.e.*, lengthwise of majority of fibers). Strength crosswise about half as great.
‡ Modulus of rupture (transverse strength)—probably somewhat higher than tensile strength.
§ Kg per cm of width. Stress in direction of warp. About half as strong when stress is in direction of filler.

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(For a key to the periodicals see end of volume)

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THERMAL INSULATING MATERIALS FOR MODERATE AND LOW TEMPERATURES

F. H. Schofield and J. A. Hall

This section covers the various types of commercial insulating materials, associated structural materials and some miscellaneous materials. For the second group of materials reference should also be made to the sections of I. C. T. dealing with these classes of materials.

In the tables below the various materials are assembled in groups which are arranged approximately in the ascending order of the lowest thermal conductivity of any material of the group.

The thermal conductivity, k, is given in 10^{-3} joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, one unit of which = 0.239×10^{-3} g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, = 0.192×10^{-3} BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. *See also* vol. I, p. 25 for other conversion factors.

Cette section comprend les types variés des matières isolantes du commerce, les matériaux de construction associés, et quelques matières diverses. En ce qui concerne le deuxième groupe de matières, il faut aussi consulter les sections des I. C. T. qui traitent de ces classes de matières.

Dans les tables ci dessous, les matières variées sont arrangés en groupes approximativement dans l'ordre ascendant de la conductibilité thermiqué la plus basse du groupe.

La conductibilité thermique, k, est donnée en 10^{-3} joule cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, une unité de celle-ci = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1}(°F, in.$^{-1}$)$^{-1}$. Voir vol. I, p. 25 pour d'autres facteurs de conversion.

Dieser Abschnitt behandelt die verschiedenen Typen von handelsüblichen Isoliermaterial, damit zusammenhängendem Material und einigem verschiedenen anderen. Für die zweite Gruppe der Materialien soll auch in dem Teil der I. C. T. nachgeschlagen werden, die diese Klasse von Materialien behandeln.

In der unteren Tafel sind die verschiedenen Materialien in Gruppen angeordnet und zwar ansteigend von dem kleinsten Wert der Gruppe für die thermische Leitfähigkeit.

Die thermische Leitfähigkeit, k, ist gegeben in 10^{-3} Joule cm^{-2} sec^{-1}(°C cm^{-1})$^{-1}$, deren Einheit = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. Umrechnungsfaktoren, Bd. I, p. 25.

Questa sezione comprende i diversi tipi di materiali isolanti che si trovano in commercio, i prodotti analoghi per costruzioni e materiali varii. Per il secondo gruppo di materiali, si consultino anche le sezioni della I. C. T., che trattano di queste classe di materiali.

Nelle tabelle seguenti, i diversi materiali sono disposti in gruppi approssimativamente secondo l'ordine della conduttività termica, crescente dalla più bassa del gruppo in su.

La conduttività termica, k, e data in 10^{-3} joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, di cui una unità = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. Vedi inoltre tomo I, p. 25, per altri fattori di conversione.

Thermal Conductivity

Material	Bulk density, g/cm³	t°C	k	Lit.
Air	0.00129	0	0.23	(19, 22)
Silk			0.40	(30)
Scrap from spinning mill	0.10_1	0	0.44_2	(26)
		50	0.52_4	
		100	0.59_5	
Braided	0.14_7	0	0.45_5	(36)
		50	0.54_7	
		100	0.60_5	
Scrap from spinning mill	0.10_0	−200	0.23_2	(18)
		−150	0.31_4	
		−100	0.37_2	
		− 50	0.43_7	
		0	0.49_5	
		50	0.55_9	
Fabric		40	0.46	(59)
"Calorox" (fluffy mineral matter)	0.064	30	0.31_8	(52)
Slag wool (mineral wool)	0.15	30	0.42	(14, 52)
	0.20	30	0.45	
	0.25	30	0.48	
	0.30	30	0.52	
With binder, waterprf. Rock cork	0.25	30	0.50	(52)
Cork	*v. infra* p. 315.			
Ashes (soft wood)		20	0.32	(32)
Rubber, hard sponge, rigid	0.087	25	0.34	(14)
	0.090	25	0.40	
	0.16	35	0.42	(55)
Cellular (expanded after vulcanising under very high gas pressure, cells unbroken)	0.09	20	0.36	(14)
Sponge (vulcanising rubber mixed with ammonium carbonate, cells broken)	0.22	20	0.54	(14)
Ebonite	1.19	−190	1.3_8	(29, 50, 12, 20, 10, 11, 50)
		− 78	1.5_7	
		0	1.6_0	
Soft, vulcanised	1.1	30	1.7_6	(32, 20)
Commercial, 40 % pure rubber		25	2.8_4	(50)
50 % pure rubber			2.2_1	(50)
67 % pure rubber			1.7_5	(50)
92 % pure rubber			1.6_8	(50)
100 % pure rubber (Plantation crepe)			1.3_4	(50)
Kapok, loosely packed	0.015	20	0.35	(52, 4, 28)
Tightly packed			0.50	
Wool	0.09	0	0.37_2	(26)
		60	0.49_7	
Pure	0.09	30	0.36_4	(9)
Pure, very loose packing	0.04	30	0.42_8	
Slightly greasy	0.14	0	0.38_4	(36)
		50	0.48_8	
		100	0.58_2	
	0.08	75	0.77	(8)
Blankets	0.08	30	0.43	(42)
Cotton, tightly packed	0.08	−150	0.37_8	(36, 18)
		0	0.55_8	
		150	0.75_8	
Fabric		40	0.80	(59)
Cotton wool, tightly packed	0.08	30	0.42	(52, 33)
Glass wool	0.22	50	0.41_8	(41)
		100	0.50_9	
		200	0.65_1	
		300	0.81_2	
Wood fiber, shredded, soft, flexible	0.09	35	0.42	(55)
Rice paper		40	0.46	(59)
Blotting paper		20	0.63	(30)
Corrugated cardboard 5 layers per in.		20	0.63	(4)

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Pasteboard	0.69	30	0.71	(52)
Cardboard, various		50	1.7–3.4	(59)
Skeleton cardboard bricks (Ewing's)		20	0.99	(14)
Felted flax fibers	0.18	30	0.47	(52)
Flax and paper lining for steel railway cars		30	0.45 to 0.65	(52)
Felt, asphalt-impregnated	0.88	30	1.01	(52)
Wood felt, flexible paper stock	0.33	30	0.52	(52)
Felted vegetable fibers	0.18	30	0.47	(52)
Wool felt	0.15	40	0.63	(50)
	0.33	30	0.52	(52)
Hair felt	0.27	30	0.36	(52)
Balsa wood, across grain	0.11_{8}	30	0.45	(52, 59)
Balsa wood, waterproofed	0.12_{8}	30	0.52	
Balsa wood, medium	0.14_{8}	30	0.55_{3}	(52)
Balsa wood, heavy	0.33	0	0.83_{9}	(52)
Pseudo balsa wood (⊥ grain)	0.25		0.67	(59)
Pseudo balsa wood (‖ grain)			1.21	(59)
Cottonseed hull fiber, loose pack	0.071	30	0.45	(52)
Eucalyptus bark fiber		0	0.45	(14)
Saragossa grass	0.15	30	0.45	(14)
	0.22	30	0.49	
Straw fibers, pressed	0.14	0	0.45_{4}	(25)
		20	0.46_{6}	
Eelgrass	0.25	30	0.46	(52)
Ceiba wood, ⊥ grain, untreated	0.11	30	0.47	(52)
Curled cattle hair, loose, soft, flex	0.088	35	0.48	(55)
Sugar cane fiber (bagasse) board	0.25	35	0.54	(55)
Pressed wood pulp board	0.19	30	0.43	(52)
Waterproof lith board (slag wool, veg. fiber, waterprf. binder)	0.20	30	0.55	(52)
Bulrush in cloth	0.14	30	0.49	(52)
Kingia australis (shredded fiber from outside layer of trunk)	0.13	30	0.49	(14)
Solid from outside		30	0.76	
Solid from inside		30	1.0_{6}	
Horsehair, compressed	0.17_{2}	20	0.50_{9}	(26)
		65	0.54_{7}	
Diatomite	v., p. 315.			
Peat, dry	0.19	30	0.52	(36)
Peat boards	0.23	20	0.58_{1}	(18)
	0.37	20	0.87_{3}	
	0.73	20	1.1_{6}	
Peat blocks	0.84	20	1.7_{4}	(18)
Charcoal	0.18	20	0.55	(4, 14, 25, 36, 38)
Sawdust, various	0.20	30	0.60	(12, 52, 36, 8)
Shavings, various	0.14	30	0.60	(52)
Leather, chamois		85	0.63	(30)
Leather, cowhide		85	1.7_{6}	(30)
Leather, sole	1.0	30	1.5_{9}	(52)
Jongdala wood (⊥ grain)		30	0.67	(14)
Jongdala wood (‖ grain)		30	1.2_{0}	
Asbestos, cork, straw and diatomite steam-pipe covering, dry, loose	0.41	0	0.69_{8}	(36)
		50	0.81_{3}	
		100	0.88_{4}	
		150	0.91_{8}	
		200	0.94_{3}	
Idem., molded with water to solid	0.69	150	1.1_{6}	(36)
		220	1.4_{0}	
Asbestos-diatomite, loose	0.55_{0}	50	0.94_{1}	(41)
	0.60_{9}	50	0.91_{8}	
	0.62_{5}	50	0.86_{0}	
	0.66_{8}	50	1.0_{6}	
	0.60_{9}	50	0.91_{8}	
	0.60_{9}	100	0.93_{0}	
	0.60_{9}	200	0.95_{8}	
	0.60_{9}	300	0.96_{5}	

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Asbestos, wool	0.40	0	0.90	(15, 36, 4)
	0.50	0	1.3_{6}	
	0.60	0	1.7_{5}	
	0.70	0	1.9_{7}	
	0.40	−100	0.68	
	0.40	0	0.90	
	0.40	100	1.0_{1}	
Asbestos, slate	1.8	50	2.2	(18)
Wood (asbestos and cement compressed)	2.0	50	3.9	(52)
Pipe coverings of asbestos felt corrugated asbestos paper, etc	0.3 to 0.5	50	0.8 to 1.0	(52, 54, 31)
Paper, thin layers with organic binder	0.50	30	0.71	(52)
Paper		20	1.6	(30, 50)
Corrugated	0.14	30	0.66	(52)
Asbestos car lining	0.43	30	0.68	(52)
Asbestos-and-plaster blocks	0.29	30	0.81_{5}	(52)
	0.47	30	1.3_{0}	
Fire felt, flexible (asbestos sheet)	0.42	30	0.86	(52)
Fire felt, rigid (asbestos sheet, cement coated)	0.68	30	0.92	(52)
Asbestos-diatomite-cork (loose)	0.33	50	0.81_{3}	(41)
	0.33	100	0.84_{8}	
	0.33	200	0.89_{0}	
Magnesia-asbestos (85 % MgO)	0.3	30	0.75	(31, 52)
Cork linoleum	0.54	20	0.80	(18)
Linoleum (dry)	1.18	0	1.7_{5}	(15)
		20	1.8_{6}	
Steel wool	0.15_{2}	55	0.80_{3}	(40)
	0.10_{1}	55	0.87_{5}	
	0.07_{6}	55	0.90_{4}	
Linen		20	0.86	(32)
Kiri wood (⊥ grain)			0.88	(59)
Pumice gravel	0.3	20	0.92	(15)
	0.6	0	1.7_{5}	(18)
		20	1.8_{6}	
Cypress wood (⊥ grain)	0.46	30	0.96	(52)
Coffee husks		30	0.98	(14)
Fuller's earth	0.53	30	1.0_{1}	(52)
Blast furnace slag	0.79	20	1.8_{6}	(18)
2 to 5 mm grain size No. 1	0.36	20	1.0_{5}	
3 cm grain size No. 2	0.36	20	1.5_{1}	
Nos. 1 and 2 mixed	0.30	20	1.2_{8}	
Spruce (⊥ grain)	0.41		1.1	(59)
Spruce (‖ grain)			2.2	(59)
Coal dust	0.73	30	1.1_{1}	(50)
		90	1.2_{5}	
White pine (⊥ grain)	0.50	30	1.1_{3}	(52)
	0.45	60	1.0_{7}	(50)
(‖ grain)		60	2.5_{7}	
Cedar (⊥ grain)	0.48		1.1_{3}	(59)
Virginia pine (⊥ grain)	0.55	30	1.3_{8}	(52, 59)
Pitch pine (⊥ grain)		30	1.4_{9}	(14)
Cement paper, plain (14 layers each 0.38 mm)	0.62	20	1.2_{7}	(50)
		50	1.3_{5}	
Cement paper, treated (12 layers, each 0.46 mm)	1.0_{2}	20	1.5_{6}	
		50	1.6_{5}	
Cement wood (sawdust and Portland cement)	0.71	0	1.2_{8}	(36)
		20	1.3_{9}	
	0.82	20	1.7_{4}	
Snow	0.50	0	$1._{3}$	(22)
	0.11	0	1.0_{7}	(24)
	0.45	0	0.49	
	0.24	0	1.6_{7}	(37)
	0.25	0	1.8_{8}	
	0.27	0	1.3_{4}	
Mahogany (⊥ grain)	0.55	30	1.3_{0}	(52)
			1.7	(35)
	0.70	20	1.6	(59)
(‖ grain)			3.1	(59)
Oak (⊥ grain)	0.61	30	1.3_{7}	(52, 59)
	0.82	0	1.9_{8}	(38)
		15	2.1_{0}	

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Oak (∥ grain)	0.82	12	3.4_9	
		20	3.6_1	(38)
		50	4.3_1	
Soil, dry		20	1.3_8	(30)
wet		20	6.7_0	
normal, including stones 2 to 7 cm	2.0_4	0	5.0_0	
		20	5.2_8	(15)
		70	5.8_2	
Garden mold, dry			2.0_1	(35)
Teak (⊥ grain)	0.64	0	1.6_8	
		15	1.7_5	(38)
		50	1.9_8	
	0.72	20	1.4	(59)
(∥ grain)	0.60	12	3.7_2	
		18	3.8_4	(38)
		50	3.9_4	
Fir (⊥ grain)	0.54	20	1.4	(38, 54, 59)
(∥ grain)	0.55	20	3.5	(38)
Walnut (⊥ grain)	0.65	20	1.4	(59)
(∥ grain)			3.3	
Baobab wood (∥ grain)		30	1.4_1	(14)
Fuller board, treated				
11 layers each 0.51 mm	1.3_9	20	1.6_1	
		50	1.7_5	
16 layers each 0.76 mm	1.1_5	20	6.1*	
		50	6.9*	
4 layers each 1.42 mm	1.0_9	20	1.4_9	
		60	1.6_6	
2 layers each 3.1 mm	0.95	20	1.4_2	
		50	1.4_6	
Fuller board soaked in transformer oil				
3 layers each 3.18 mm	1.0_1	20	2.1_2	
		50	2.2_7	
		50	5.1_5*	
Fuller board, untreated				
15 layers each 0.38 mm	1.3_8	20	2.6_8	(50)
		50	2.6_8	
7 layers each 7.6 mm	1.2_6	20	2.5_5	
		50	2.6_8	
16 layers each 7.6 mm	1.2_2	20	6.2_8*	
		50	6.6_2*	
21 layers each 0.25 mm	1.3_9	20	2.6_0	
		50	2.8_9	
4 layers each 1.42 mm	1.1_5	20	1.9_5	
		50	2.1_5	
9 layers each 1.42 mm	1.1_5	20	6.3_7*	
		50	6.9_0*	
3 layers each 3.18 mm	1.0_1	20	1.4_5	
		50	1.6_2	
Facing cement (Mg oxychloride)		0	1.4_6	(14)
Boxwood	0.90	20	1.5_1	(3)
		100	1.7_2	
Coke dust	1.0_0	20	1.5_1	(18)
Concrete, pumice gravel and cement	0.60	20	1.5_1	(15)
		30	1.6_8	
Pumice pebbles 9, fine sand 2, Portland cement 1	1.1_7	85	2.3	(8)
1:12, air-dried 2 weeks	2.0_5	0	7.6_6	
		20	8.1_5	(38)
		30	8.3_6	
Granulated cork 3, fine sand 2, Portland cement 1	1.2_7	85	2.5_8	(8)
Slag 9, fine sand 2, Portland cement 1	1.5_2	85	2.9_6	(8)
Lime mortar, "Beffes No. 3"	1.7_5	90	3.5_1	(8)
Cement mortar, Portland No. 1	1.7_2	90	3.3_6	(8)
Portland No. 2	1.8_9	90	5.3_5	(8)
Concrete, blast furnace slag 9 pts vol., cement 1 pt. vol	0.55	50	2.2_1	(36)
Concrete	1.6	0	8.3_6	(36)
Concrete plus moisture 10 % by volume	2.3	0	12.1	
Cement mortar 10.5 mm thick, including 4 mm reinforcing metal	2.1_2	90	5.7_7	(8)
12.0 mm thick, including 3 mm reinforcing metal	1.9_7	90	5.9_7	(8)
Concrete, gravel 9, fine sand 2, cement 1	1.9_9	90	6.4_0	(8)

* Longitudinally.

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Concrete, gravel 9, fine sand 2, cement 1, air-dried six months	2.1_8	20	7.6_5	(15)
Portland cement	2.0	60	3.0	(36, 30)
Ash (⊥ grain)	0.74	20	1.7	(59)
(∥ grain)			3.1	(59)
Bricks, very porous, dry	0.71	20	1.7_4	(18)
	0.81	20	1.9_8	
Bricks, very porous, moisture 1.2 % volume	0.74	20	1.6_9	
Moisture 5.8 % volume	0.79	20	2.4_4	(7)
Moisture 21.5 % volume	0.94	20	3.9_6	
Bricks, hand-made, dry	1.5_4	0	3.8_2	(38)
Bricks, machine-made, dry	1.6_7	0	5.1_2	
		40	5.3_5	(38)
		80	5.4_6	
	1.6_2	50	4.8_1	(25)
Bricks, machine-made				
Moisture 0.8 % volume		50	4.9_9	(25)
Moisture 1.2 % volume		50	9.5_6	
Old brick masonry	1.8_5	0	3.8_2	
		20	4.0_7	(15)
		47	4.4_2	
Maple (⊥ grain)	0.72	30	1.7_0	(52, 50)
(∥ grain)	0.72	30	4.3_5	(50)
Fish paper				
21 layers each 0.25 mm	1.0_6	20	1.7_2	
		50	1.8_1	
75 layers each 0.25 mm	1.0_6	20	4.8_0*	
		50	5.0_3*	(50)
10 layers each 0.58 mm	1.0_8	20	2.0_1	
		50	2.1_6	
6 layers each 1.4 mm	1.0_1	20	2.3_7	
Paraffined fish paper				
30 layers each 0.18 mm	1.0_6	20	1.9_2	
		50	2.0_3	
15 layers each 0.38 mm	1.1_6	20	2.1_7	(50)
		50	2.1_9	
8 layers each 0.97 mm	1.1_5	20	2.0_7	
Powdered graphite				
100 mesh	0.48	40	1.8_3	
40 mesh	0.42	40	3.8_5	(50)
20 mesh on 40 mesh	0.70	40	$11._9$	
Cement paper and mica				
No. 226, 5.7 mm thick		20	1.8_5	
		50	1.9_3	
No. 227, 5.05 mm thick		20	1.9_5	
		50	2.0_8	
No. 247, 5.7 mm thick		20	2.1_0	(50)
		50	2.1_8	
No. 227, 13 mm thick		20	9.3_2*	
		50	9.8_8*	
Fish paper and mica		60	2.0	(50)
Celluloid, white	1.4	30	2.1_6	(32)
Fiber, vulcanized		50	2.1–3.3	(59)
Fiber, white	1.2	20	2.7_6	(59)
		50	2.9_1	(59)
Micanite		30	2.1–4.2	(59)
Varnished cambric, tacky				
30 layers each 0.23 mm	1.1_7	20	2.1_7	
		50	2.2_8	
75 layers each 0.23 mm	1.1_7	20	4.3_0*	(50)
		50	4.3_8*	
Varnished cambric, dry	1.2_4	20	2.1_0	
30 layers each 0.23 mm		50	2.2_3	
Kraft paper and mica, No. 312, 13.2 mm thick		20	$11._2$*	
		50	$11._3$*	(50)
Idem., 5.6 mm thick		50	2.2_3	
Paraffin wax	0.89	30	2.3_0	[illegible]
Micarta folium, No. 249, 5.9 mm thick		50	2.3_1	[illegible]
14.5 mm thick		50	$11.$[illegible]*	
Cellulose, compressed	1.4_2	15	2.4_4	[illegible]

* Longitudinally.

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Presspan		54	2.49	(49)
Black bias cloth, 22 layers each 0.23 mm	1.26	50	2.51	(50)
80 layers each 0.23 mm	1.26	20	3.82*	
		50	4.26*	
Lignum-vitae	1.16	20	2.52	(3)
		100	3.02	
Mica tape, 30 layers each 0.15 mm	1.06	50	2.63	(50)
30 layers each 0.20 mm	1.12	50	2.68	
120 layers each 0.15 mm	1.06	50	14.5*	
Plaster of paris, powder		20	10.9	(30)
Plaster of paris, cast		20	3.0	
Fine river sand, dried	1.52	0	3.02	(15)
		20	3.26	
		160	3.84	
Fine river sand with normal moisture content (ca.6.9 % by weight)	1.64	20	11.3	(15)
		50	11.5	
Gypsum plaster	0.74	30	3.35	(52)
Plaster	1.69	20	7.9	(15)
Mica		41	3.6	(49)
Mica, various		50	4.2–5.9	(59)
Gravel	1.85	20	3.7	(15)
Bitumen		30	4.2 to 6.3	(14)
Flooring composition		30	8.5	(14)
Greenhart	1.08	20	4.69	(3)
		100	4.61	
Water	1.0	20	5.9	(22)
Glass, lead		15	6.0	(33)
Glass, soda	2.59	20	7.2	(3, 33, 50)
		100	7.6	
Limestone, Villers-Adam, soft	1.81	90	6.01	(8)
Lerouville, hard	2.55	90	12.9	(8)
Fine-grained, dry	1.66	0	6.29	(38)
		25	6.86	
		40	7.21	
Coarse-grained, dry	1.99	0	8.38	(38)
		25	9.30	
		40	9.90	
Caen stone			18.0	(20)
Limestone		0	19 to 24	(39)
		100	16 to 21	
		350	13 to 15	
Asphalt composition	2.12	0	6.05	(38)
		10	6.52	
		20	6.98	
		30	7.44	
Alumina (compressed powder)	1.84	47	6.77	(27)
Chalk			9.2	(20)
Porcelain		90	10.4	(30)
Slate, ⊥ cleavage		95	15.0	(30)
Slate, ∥ cleavage			13.2 to 15.1	(20)
			23.0 to 27.2	
Sandstone, grey, natural, freshly cut	2.26	10	15.5	(38)
		20	16.7	
		40	18.4	
Sandstone, air-dried six months	2.25	0	12.2	
		20	12.9	
		30	13.2	
Basalt		20	20	(53, 46, 17, 39)
Ice	0.92	0	22	(22, 34, 48)
Granite	2.8		22	(20)

Hollow Tile Ceiling (4). *k* at 10°C.—*Sample* A: Top tile 1, air 2.5, tile 1, air 11, tile 1, air 2.5, tile 1 cm, $k = 6.86$. *Sample* B: Top tile 0.85, air 0.8, tile 0.85, air 13, tile 0.85, air 0.8, tile 0.85, concrete 3 cm, $k = 6.76$. *Sample* C: Same as B but with the 13 cm air space filled with concrete, $k = 11.9$. Heat flow up.

THERMAL CONDUCTIVITY OF DIATOMITE

d \ t	0°C	100°	200°	300°	400°	Remarks
0.20	0.52	0.62	0.73	0.83	0.94	Average values. The use of binding materials will increase the conductivity by amounts varying up to 100% (5, 14, 18, 36, 38, 44, 52)
0.30	0.61	0.74	0.86	0.98	1.11	
0.40	0.73	0.88	1.03	1.18	1.34	
0.50	0.86	1.03	1.21	1.39	1.57	

THERMAL CONDUCTIVITY OF CORK

d \ t	0°C	20°	40°	60°	80°	100°	Remarks
0.05	0.32	0.34	0.36	0.37	0.39	0.41	Average values. Use of binding materials gives increases up to 30 % (4, 8, 14, 18, 26, 36, 38, 44, 52, 57, 58)
0.10	0.37	0.39	0.41	0.43	0.45	0.47	
0.20	0.46	0.49	0.52	0.54	0.57	0.60	
0.30	0.56	0.60	0.63	0.66	0.69	0.73	
0.35	0.61	0.65	0.68	0.72	0.75	0.79	

THERMAL CONDUCTIVITY OF POWDERS UNDER REDUCED AIR PRESSURES

For granular powders, Smoluchowski gives the following formula connecting the thermal conductivity *k* with the pressure *p* of the gas in the interstices:

$$k = A \log (1 + ep)$$

where, for a given gas *A* is a constant depending on the arrangement of the grains and *e* on the material of which they are composed. For spongy powders this law does not hold. In the following table the conductivity of various powders (having the indicated average grain diameters in mm) is given in hectoerg ($=10^{-5}$ joule) per cm² per sec per (deg. C per cm). Smoluchowski, *Acad. Sci. Crac. Bull.* **5b**: 129; 10 and **8a**: 548; 11.

Pressure mm Hg	Quartz 0.26 mm	Emery 0.11 mm	Quartz 0.09 mm	Lycopodium 0.03 mm	Zinc 0.028 mm	Iron 0.025 mm	Rice 0.003 mm	Diatomite	Lampblack
0.05	1.4		0.6						
0.10	2.8		1.1					1.3	
0.20	5.6	2.0	2.1	1.0	1.1	0.9	0.6	2.1	1.0
0.50	11.7	5.0	4.8	2.2	2.4	1.9	1.3	3.9	2.0
1.0	20.1	8.8	8.8	4.1	4.4	3.4	2.3	5.9	3.0
2.0	33.5	15.1	15.1	6.9	7.5	5.9	3.7	8.8	4.2
5.0	61	28.5	29.7	13.1	15.1	12.2	7.1	13.4	6.6
10	88	43.9	48.1	20.5	25.1	20.5	10.9	17.6	8.4
20		66	71	28.9	40.1	33.5	16.8	21.8	10.5
50		88		38.9	67	59	24.7	26.8	13.8
100		105		43.9	88	77	31.8	30.1	16.8
200		118		46.0	109	100	38.5	33.1	18.8
400		121		48.1	126	121	43.9	34.8	21.8
700		128		50	136	132	48.1	35.6	23.4
Solid					111000	60100			

THERMAL DIFFUSIVITY

Thermal diffusivity, $\Delta t = k/dc$, where k = thermal conductivity, d = bulk density, c = specific heat. $\Delta t = 10^{-3} \times A$ cm² sec⁻¹

Material	A	Lit.
Gutta-Percha, 43°	0.486	(45)
Ebonite	0.928	(47)
Coal	1.13	(17, 34)
Rubber, 26°	1.42	(45)
Water, 20°	1.43	(22)
Snow (d = 0.19), 0°	2.50	(1)
(d = 0.33), 0°	4.60	(1)
(densely packed), 0°	4.1	(21)
Gypsum	3.0	(17)
Soil, very dry	3.1	(22)
Garden sand	3.6	(6)
Sandy clay	5.1	(6)
Coarse sand	7.6	(6)
Garden sand	8.7	(6)

THERMAL DIFFUSIVITY.—(*Continued*)

Material	A	Lit.
Frozen mold	9.2	(56)
Gravel	12.5	(56)
Sandy loam	13.6	(6)
Porphyritic trachyte	5.9	(2)
Trap rock	7.86	(51)
Sandstone	10.7	(51)
Marble	11.1	(17, 46)
Ice, 0°	11.4	(34)
Basalt	11.5	(46)
Granite	13.1	(34, 46)

ADSORBED MOISTURE IN EQUILIBRIUM WITH AIR OF VARIOUS HUMIDITIES (60)

	Moisture content (per cent of dry weight)				
Rel. humidity, %	15	30	50	70	90
Absorbent cotton (cottonwool)	8.9	10.1	20.6	22.2	25.8
Cotton cloth	2.99	4.56	6.7	9.6	13.5
Raw silk	5.0	7.1	9.0	13.3	19.0
Paper pulp (pine)	4.55	6.3	7.9	9.5	12.0
Kraft paper	2.50	3.85	5.4	7.0	9.2
Sole leather	7.0	11.1	16.0	20.6	29.2
Feathers	5.0	6.4	8.1	10.4	12.7
Rubber (solid tire)	0.17	0.28	0.60	0.74	0.99
Fuller's earth	4.54		7.5		15.6
Asbestos fiber	0.22	0.26	0.40	0.62	0.84
Diatomite	0.50	0.88	1.40	2.00	3.19
Kaolin	0.30	0.60	0.92	1.06	1.27
Glass wool	0.09	0.09	0.17	0.23	0.40
Lampblack	2.48	3.42	3.85	4.31	6.0

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(For a key to the periodicals see end of volume)

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THERMAL INSULATING MATERIALS FOR HIGH TEMPERATURE

GORDON B. WILKES

	Bulk density, g/cm^{-3}	Max. safe temperature for continuous use, °C	Mean coefficient of thermal conductivity* 600 to 25°C
Insulating blocks composed chiefly of			
1. Diatomaceous earth and asbestos	0.32–0.40	700– 900	0.00072–0.00096
2. Rock and slag wool mixtures	0.26–0.40	700– 900	0.00090–0.00120
Insulating bricks			
1. Diatomaceous earth (natural)	0.48	850–1000	0.00066–0.00108
2. Clay, diatomaceous earth and cork (fired)	0.43	850–1000	0.00096–0.00120
3. Diatomaceous earth and clay (fired)	0.64–0.96	1100–1300	0.00150–0.00360

* Joule, cm^{-2} sec^{-1} (°C, cm^{-1}).

Values taken from U. S. Bur. Stand., trade catalogs of The Celite Products Co., Armstrong Cork and Insulation Co., and mainly from determinations in Heat Measurement Laboratory, Mass. Inst. Tech.

RAW MATERIALS OF THE PAINT AND VARNISH INDUSTRIES

AVERAGE BULKING VALUES AND SPECIFIC GRAVITIES OF THE MORE COMMON DRY PIGMENTS USED IN THE PAINT INDUSTRY

Henry A. Gardner and H. C. Parks

	Specific gravity	Wt. per solid gal., lb.	1 lb. bulks, gal.
Basic carbonate white lead	6.81	56.73	0.01763
Basic sulfate white lead	6.41	53.40	0.01873
Zinc oxide	5.66	47.15	0.02121
Zinc oxide, leaded (contains 35% basic lead sulfate)	5.95	49.56	0.02018
Lithopone (*ca.* 28% ZnS, 72% $BaSO_4$)	4.30	35.82	0.02792
Titanox (25% TiO_2, 75% $BaSO_4$)	4.30	35.82	0.02792
Talc (contains *ca.* 5% $CaCO_3$)	2.85	23.74	0.04212
Barytes	4.45	37.07	0.02698
China clay	2.62	21.82	0.04583
Silica	2.65	22.07	0.04531
Whiting ($CaCO_3$)	2.71	22.57	0.04431
Venetian red (20% Fe_2O_3)*	3.05	25.41	0.03935
Red oxide (40% Fe_2O_3)	3.45	28.74	0.03479
Red oxide (95% Fe_2O_3)	4.95	41.23	0.02425
Indian red (90% Fe_2O_3)	4.92	40.98	0.02440
Ferric oxide (98% Fe_2O_3)	5.15	42.90	0.02331
Tuscan red	3.95	32.90	0.03040
Ochre	2.80	23.32	0.04288
Sienna, raw	3.27	27.24	0.03671
Sienna, burnt	3.95	32.90	0.03040
Umber, raw	2.68	22.32	0.04480
Umber, burnt	3.80	31.65	0.03160
Brown oxide (50% Fe_2O_3)	3.35	27.91	0.03583
Mineral brown (45% Fe_2O_3)	3.34	27.82	0.03595
Chromium oxide	4.95	41.23	0.02425
Litharge	9.40	78.30	0.01277
Orange mineral	8.80	73.30	0.01364
Red lead	8.80	73.30	0.01364
Pure paranitraniline toner	1.50	12.50	0.08000
Para red 10% (on lime and barium base)	2.65	22.07	0.04531
Pure toluidine red toner	1.49	12.41	0.08058
Chrome green, C. P.	3.90* 5.08*		
American blue (iron cyanide blue)	1.85	15.41	0.06489
Ultramarine blue	2.35	19.58	0.05107
Chrome yellow, C. P*	6.00*		
Lampblack	1.78	14.83	0.05743
Carbon black	1.81	15.08	0.06631
Drop black	2.64	21.99	0.04548
Graphite	2.36	19.66	0.05086
Mineral black filler (clay base with from 15 to 30% carbon)	2.71	22.57	0.04431
Zinc dust	7.06	58.81	0.01700
Aluminum dust	2.64	21.99	0.04548
Lead dust	11.09	92.38	0.01082

* These will vary widely according to composition required for shade or tone and character of base.

Red and brown oxides of variable composition. Matter other than iron oxide may be clay, silica, etc.

AVERAGE CONSTANTS OF OILS USED IN PAINT AND VARNISH INDUSTRY

Henry A. Gardner and L. L. Steele

Oil	Species	Specific gravity $\frac{15.5°C}{15.5°C}$	Iodine (Hanus) No.	Saponification No.	Acid No.	Refractive index 25°C
	Vegetable and seed oils					
Chia	*Salvia hispanica*	0.934	196	192	0.6	1.486
Corn	*Zea mays*	0.921	125	190	4.0	1.480
Cottonseed	*Gossypium herbaceum*	0.924	112	194	0.9	1.472
Hempseed	*Cannabis sativa*	0.927	149	191	4.0	1.482
Kapok seed	*Eriodendron anfractuosum*	0.924	119	196		
Linseed (boiled)	*Linum usitatissimum*	0.941	172	187	2.7	1.490
Linseed (heavy bodied)	*Linum usitatissimum*	0.968	133	189	2.8	1.497
Linseed (lithographic)	*Linum usitatissimum*	0.970	102	199	2.7	1.498
Linseed (raw)	*Linum usitatissimum*	0.934	186	191	2.0	1.480
Oticia	*Conepia grandifolia*	0.969	180	189	8.0	
Palo maria	*Calophyllum inophyllum*	0.934	97	193	46.0	1.474
Perilla	*Perilla ocimoides*	0.934	200	188	2.0	1.487
Poppyseed	*Papaver somniferum*	0.926	134	192		
Raisinseed (grapeseed)	*Vites*, spp.	0.926	133	193	4.5	1.471
Rosin oil	*Pinus palustris*	0.964	69	36	32	
Rubberseed	*Hevea brasiliensis*	0.924	137	193	57	
Sesame	*Sesamum orientale & indicum*	0.924	110	190	1.5	
Soya bean	*Soja hispida*	0.924	129	189	2.3	1.481
Sunflower	*Helianthus annuus*	0.924	125	189	7.5	1.480

Oil	Species	Specific gravity $\frac{15.5°C}{15.5°C}$	Iodine (Hanus) No.	Saponification No.	Acid No.	Refractive index 25°C
		Nut oils				
Lumbang (candlenut)	*Aleurites moluccana*	0.927	152	192	1.0	1.477
Lumbang (soft)	*Aleurites trisperma*	0.938	164	194	4.4	1.493
Peanut	*Arachis hypogaea*		102	193	2.2	1.479
Tung (American)	*Aleurites fordii*	0.941	166	195	0.2	1.517
Tung (Chinese)	*Aleurites fordii*	0.944	165	192	4.8	1.517
Walnut	*Juglans regia*	0.926	143	193		1.477
Wood (Japanese)	*Aleurites cordata*	0.934	154	193	0.9	1.508
		Marine animal oils				
Channel catfish		0.923	123	192	11	1.474
Fur seal	*Phoca vitulina*, etc.	0.925	132	182	9	1.477
Grayfish		0.916	135	180	2	1.470
Menhaden	*Alosa menhaden* (*Brevoortia tyrannis*)	0.932	158	187	4	1.485
Salmon	*Salmo salar*	0.927	159	183	10	1.479
Sardine	*Clupea sardinus*	0.919	135	177	10	1.480
Shark		0.910	133	160	5	1.482
Shark liver	*Borealis scymnus*	0.922	136	62	1.5	1.471
Skate liver	*Squatina vulgaris*	0.932	152	180	2	1.471
Tuna fish		0.933	184	190	0.5	
Whale	*Balœna*	0.924	148		9	1.482
Yellow tail fish	*Seriola dorsalis*	0.932	180	190	0.6	

TOXICOLOGY OF GASES AND VAPORS

R. R. Sayers

EFFECTIVE CONCENTRATIONS AND PROPERTIES

In the following paragraphs the numbers in bold face have the following significance:

1. Boiling point.
2. Percentage fatal in 30 minutes or less.
3. Percentage causing dangerous illness in 0.5 to 1 hour.
4. Percentage that can be borne without severe effects for 0.5 to 1 hour.
5. Maximum safe concentration.
6. Properties (1).
7. Portal of entry (1).
8. Symptoms (1).
9. Occupations (1).

Acrolein, $CH_2:CHCHO$.—**1.** 52°. **2.** 0.001 (2). **5.** 0.00033 (2). **6.** Colorless, pungent fluid, of fiery taste. **7.** As vapor, through organs of respiration and mucous membranes. **8.** Itching in the throat; irritation of eyes, exciting lachrymation; conjunctivitis, irritation of the air passages, bronchial catarrh. **9.** Manufacture of lard, linoleum, stearic acid; bone and fat rendering, galvanizing, tallow refining, tinsmithing, varnish boiling.

Ammonia, NH_3.—**1.** −35.5°. **3.** 0.25–0.45 (3). **4.** 0.03 (3). **6.** Colorless gas of sharply penetrating odor. **7.** As gas, through organs of respiration. Seldom pure, mostly in combination with other gases. Immediate effects on the conjunctiva and the cornea. **8.** Acute inflammation of the respiratory organs, cough, edema of the lungs, chronic bronchial catarrh, redness of the eyes, increased secretion of saliva, retention of urine. **9.** Manufacture of acetylene, ammonium salts, artificial ice, artificial silk, bone-black, dyes, shellac, soda, varnish; work around coke-ovens, refrigerating plants, sewers; bronzing, dyeing, galvanizing, gas purifying, mercerizing, shoe finishing, sugar refining, tinsmithing; work with glue, illuminating gas.

Aniline, $C_6H_5NH_2$.—**1.** 184.4°. **4.** 0.00004–0.00006 (3). **6.** Colorless oil acquiring tint on exposure to air and light. **7.** Absorption through skin, directly or by saturation of clothing; absorption through respiratory organs as volatile particles and impalpable dust; through digestive organs. **8.** Pallor of skin, vertigo, unsteady gait, loss of appetite, increased frequency of respiration, anemia, slowing of the pulse, eczematous eruptions, bloody urine, spasmodic muscular pains, cyanosis. **9.** Manufacture of aniline, artificial leather, calico, explosives, coal-tar products, dyes, paint, colored pencils; vulcanizing, tanning, printing, typesetting, photography, painting, lithography; work with feathers; compounding, mixing, reclaiming rubber, and work in press rooms.

Arsine, AsH_3.—**1.** −54.8°. **2.** 0.05 (2). **5.** 0.001 (2). **6.** Colorless, extremely offensive gas, with the odor of garlic. **7.** As gas, through respiratory organs, generally mixed with hydrogen. **8.** General malaise, difficult breathing, fainting fits, gastric disturbances, jaundice, bluish discoloration of the mucous membrane, pain in the region of spleen and kidney, darkened urine, fetor of the mouth resembling garlic. **9.** Manufacture of dry batteries, dimethyl sulfate, dyes, fertilizer, nitroglycerin, shoddy, zinc chloride; acid dipping, filling toy balloons, bronzing, enamelling, galvanizing, lead and lime burning, pickling, metal refining, tinsmithing; work with aniline, sulfuric acid, submarine storage batteries; ferro-silicon work.

Benzene, C_6H_6.—**1.** 80.2°. **4.** 0.001–0.0015 (3). **5.** 0.0005 (3). **6.** Unstable, extremely volatile, colorless fluid, burning with a bright sooty flame. A coal tar product. **7.** As vapor, through the respiratory organs; re-absorption through the skin. **8.** Headache, vertigo, anemia, muscular tremor, scarlet lips, spots of extravasated blood in the skin, irritant cough, fatty degeneration of liver, kidneys and heart. **9.** Manufacture of aniline, artificial leather, dry batteries, carbolic acid, colors, dyes, explosives, fertilizer, lacquer, paint, rubber tires, shellac, shoes,

smokeless powder, varnish; vulcanizing, coal-tar still cleaning, photography, photoengraving, painting, lithography, gilding, electroplating, dry cleaning, leather and fertilizer degreasing, pottery decorating, case scrubbing, bronzing; compounding, drying, mixing, washing, reclaiming, treading rubber; mixing rubber cement, cementing rubber shoes; work with benzol stills, coke ovens, coal tar, feathers, illuminating gas, glue, mordants.

Bromine, Br_2.—**1.** 58.6°. **2.** 0.1 (3). **3.** 0.004–0.006 (3). **4.** 0.0004 (3). **5.** 0.0001 (3). **6.** Fuming liquid with an extremely disagreeable odor. **7.** As gas, through the respiratory organs. **8.** Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin. **9.** Manufacture of dyes; chemical and pharmaceutical industries.

Carbon Disulfide, CS_2.—**1.** 46.2°. **3.** 0.001 (3). **4.** 0.0002–0.0003 (3). **5.** 0.0001 (3). **6.** When pure, a limpid, highly refractive, volatile fluid, having an odor like chloroform; imperfectly refined, it is pale yellow, with an offensive odor. **7.** As vapor, through respiration; as fluid, through the skin. **8.** Headache, pain in the extremities, trembling, deafness, reduction of the reflexes, accelerated heart action, nausea, digestive trouble, emaciation, disturbance of sense of vision, excitement and violent temper followed by depression, hyperstimulation of the sexual instinct, later its abnormal decline, chronic dementia. **9.** Manufacture of ammonium salt, artificial silk, carbon disulfide, celluloid, insecticide, matches, paint, putty, smokeless powder; asphalt testing, cementing rubber shoes, rubber cement mixing, dry cleaning, enamelling, oil extracting, tallow refining, sulfur extracting, vulcanizing, rubber drying and reclaiming, work with paraffin and glue.

Carbon Dioxide, CO_2.—**1.** −78.2°. **2.** 30.0 (3). **3.** 6.0–8.0 (3). **4.** 4.0–6.0 (3). **5.** 2.0–3.0 (3). **6.** Specifically dense, odorless, colorless gas, collecting near the ground or floor. **7.** As gas, by inhalation. **8.** Anemia, cyanosis, headache, drowsiness, vertigo, tinnitus, and general nervousness. **9.** Manufacture of alkali salts, carbon dioxide, fertilizer, pottery, soda, starch, wine, white lead, yeast; blacksmithing, brass founding, brewing, brick, charcoal and lime burning, lime kiln charging, mining, sugar refining; work in boiler rooms, caissons, drying rooms, silos; work around furnaces, sewers.

Carbon Monoxide, CO.—**1.** −190°. **2.** 0.5–1.0 (7). **3.** 0.2–0.3 (3). **4.** 0.05–0.10 (3). **5.** 0.04 (7). **6.** Colorless, tasteless gas, odorless in diffused state, burning with a blue flame in air. **7.** As gas, through the respiratory organs. **8.** Stage 1 (7): Tightness across forehead, dilatation of cutaneous vessels, headache (frontal and basal), throbbing in temples, weariness, weakness, dizziness, nausea and vomiting, loss of strength and muscular control, increased pulse and respiration rates, collapse. Stage 2: Increased pulse and respiration, fall of blood pressure, loss of muscular control, especially sphincters, loss of reflexes, coma usually with intermittent convulsions, Cheyne-Stokes' respiration, slowing of pulse, respiration slow and shallow, cessation of respiration, death. **9.** Manufacture of acetylene, carbide, celluloid, cores (founding), felt hats, incandescent lamp filaments; baking, blacksmithing, brass founding, cable splicing, calico printing, charcoal burning, charging (zinc smelting), chimney sweeping, copper smelting, enamelling, incandescent lamp finishing; work with bisque kilns, coke ovens, coal tar; work in drying and boiler rooms.

Carbon Tetrachloride, CCl_4.—**1.** 76.74°. **2.** 0.03–0.04 (3). **3.** 0.015–0.02 (3). **4.** 0.0025–0.004 (3). **5.** 0.001 (3). **6.** Colorless liquid with pleasant odor, having a narcotic action somewhat similar to chloroform (11). **7.** As vapor, through the respiratory organs. **8.** Nausea, vomiting, abdominal pain, stupor deepening into coma, absence of reflexes, clonic convulsions, weak pulse, increased temperature and death (11). **9.** Used in industry as a rubber solvent, an ingredient of certain types of paint, a fire extinguisher, and a shampooing agent.

Chlorine, Cl_2.—**1.** −33.6°. **2.** 0.10 (3). **3.** 0.004–0.006 (3). **4.** 0.0004 (3). **5.** 0.0001 (3). **6.** Yellowish-green, suffocating gas of penetrating odor, whose water solution is a greenish-yellow. **7.** As gas, through the respiratory organs. **8.** Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin, chloracne. **9.** Manufacture of alkali salts, brooms, chloride of lime, chlorine, disinfectants, dyes, phosgene, sulfur and zinc chloride; pulp beating, bleaching, calico printing, laundry work, photography.

Chloroform, $CHCl_3$.—**1.** 61.2°. **2.** 0.03–0.04 (3). **3.** 0.007 (3). **4.** 0.0025–0.003 (3). **5.** 0.001 (3). **6.** Heavy colorless liquid, with characteristic odor and sweet taste; used as an anesthetic (11). **7.** As vapor, through the respiratory organs. **8.** In anesthesia the untoward symptoms are shallow or irregular respiration, sudden cessation of respiration, pulse either very slow or very rapid, dilatation of the pupils, cyanosis, asphyxia leading to dilatation of the heart, vagus stimulation, and finally failure of heart due to asphyxial condition. In delayed poisoning there is great prostration, delirium, coma, death (11). **9.** Chloroform manufacture, but the principal hazard is in its use as an anesthetic.

Chloropicrin, CCl_3NO_2.—**1.** 112°. **2.** 0.05 (2). **3.** 0.002 (2). **4.** 0.0001 (2). **6.** Colorless oil, insoluble in water. Sufficiently volatile to keep the strata of air above it thoroughly poisonous, and persistent enough to be dangerous after 5 or 6 hours. **7.** As gas, through the respiratory organs. **8.** Lachrymatory and respiratory irritant, with specific action on the vomiting center. Causes coughing, nausea, vomiting, and in large quantities unconsciousness. Secondary effects are bronchitis, shortness of breath. **9.** Warfare.

Dichlorodiethyl Sulfide, $(CH_2ClCH_2)_2S$.—**1.** 215–217°. **5.** 0.002 (2). **6.** Oily fluid with sharp odor. Its peculiar property of blistering the skin, combined with its high persistency, makes it the most valuable war gas known. **7.** As vapor, through the respiratory passages, and through the skin. **8.** Conjunctivitis and superficial necrosis of the cornea; hyperemia, edema and, later, necrosis of the skin, leading to skin lesion of great chronicity; congestion and necrosis of the epithelial lining of the trachea and bronchi. Systemic effects due to the absorption of the substance into the blood stream and its distribution to the various tissues of the body (4). **9.** Warfare.

Hydrogen Chloride, HCl.—**1.** −82.9°. **2.** 0.5 (2). **3.** 0.15–0.2 (3). **4.** 0.005–0.01 (3). **5.** 0.005 (2). **6.** Pure HCl is a colorless gas that fumes when open to the air, forming a dense, acid, white mist. The crude commercial acid is, for the most part, impure, containing arsenic among other mixtures. **7.** Action on skin and nasal mucous membrane; seldom as vapor affecting the respiratory organs. **8.** Irritation of mucous membranes, conjunctivitis, coryza; pharyngeal, laryngeal, and bronchial catarrh; dental caries. **9.** Manufacture of alkali salts, ammonium salts, aniline, dry batteries, camphor, carbolic acid, dyes; dipping, mixing, recovering, transporting acid; cartridge dipping, shoddy carbonizing, calico printing, acid finishing (glass).

Hydrogen Cyanide, HCN.—**1.** 26.5°. **2.** 0.048 (9). **3.** 0.012–0.024 (9). **4.** 0.005–0.006 (3). **5.** 0.002–0.004 (3) **6.** Colorless, highly volatile fluid, of penetrating, pungent, and irritating odor. **7.** As gas, through the respiratory organs; also through the epidermis. **8.** Headache, vertigo, unsteadiness of gait, nausea, loss of appetite, disturbance of gastric and intestinal functions, slowing of the pulse, albuminuria. **9.** Manufacture of ammonium salts, celluloid, dyes; acid dipping, blacksmithing, browning (gun barrels), calico printing, case hardening, electroplating, fulminate mixing, gas purifying, gold refining, photog-

raphy, pickling, silver refining, tanning, tempering; work around blast furnaces, and with illuminating gas.

Hydrogen Sulfide, H_2S ([10]).—**1.** −60.2°. **2.** 0.06–0.1 ([10]). **3.** 0.05–0.07 ([3]). **4.** 0.02–0.03 ([3]). **5.** 0.01–0.02 ([10]). **6.** Colorless gas with odor of rotten eggs in low concentration; burns with bluish flame forming SO_2 and water; mixed with 7 parts air, explodes with violence when ignited. **7.** As gas, through the respiratory organs. **8.** Poisoning is of two types—acute and subacute—causing asphyxiation and irritation (conjunctivitis, bronchitis, pharyngitis, and depression of the central nervous system), respectively. In low concentration the symptoms are headache, sleeplessness, dullness, dizziness, and weariness; pain in the eyes, followed by conjunctivitis, is fairly constant; bronchitis and pains in the chest are frequent. Further poisoning produces depression, stupor, unconsciousness and death. Spasms—clonic and tonic—are present. Death from asphyxia is caused by paralysis of respiratory center, while death from subacute poisoning is associated with edema of the lungs. **9.** Manufacture of alkali salts, celluloid, dyes, fertilizer, matches, soda, sodium sulfide, starch, artificial silk; bronzing, cable splicing, flax retting, gas purifying, petroleum refining, pyrites burning, sugar refining, tanning; work around blast furnaces; work with glue, illuminating gas, sewers.

Iodine, I_2 ([11]).—**1.** 184.35°. **4.** 0.0003 ([3]). **5.** 0.00005–0.0001 ([3]). **6.** At ordinary temperatures gives off invisible vapor very irritating to the nose and eyes ([1]). **7.** As vapor. **8.** Inflammation of the lungs and pulmonary edema. **9.** Manufacture of iodine.

Mercury, Hg.—**1.** 357.33°. **5.** Less than 0.000125 causes symptoms of poisoning after daily exposure for 2 or 3 months ([5]). **6.** Silver-white, shining metal, unchangeable in air, but evaporating at house temperature ([6]). **7.** Through the uninjured skin, and the respiratory organs in the form of vapor and dust (amalgam dust, dust of the compounds of mercury) ([6]). **8.** Industrial mercurial poisoning is a chronic poisoning occasioned by work in this metal for a long period. The first symptom is generally increased ptyalism, with swelling and inflammation of the gums and of the buccal mucous membrane, often with the formation of rodent ulcers; frequently disturbances of digestion, lassitude and pallor. With further absorption of the metal, "erethism" supervenes—a peculiar psychic excitability (timorousness, bewilderment, irritability), tremor. Death may result in the worst cases in consequence of the violent tremor and spasms affecting the entire body; in other cases increasing weakness ([6]). **9.** Mining and smelting of quicksilver; mirror plating, amalgam gilding and silvering; manufacture of thermometers, barometers, manometers, incandescent electric lamps, Roentgen and Hittorf tubes, mercurial vapor lamps, salts of mercury, amalgams, colors, pharmaceutic products, antiseptic dyes, inflammable materials, explosives; use of mercury salts, especially in the hare's fur business and felt hat manufacture; photography, steel engraving ([6]).

Nitrogen Oxides (Expressed in Percentages as Nitric Acid) NO.—**1.** −153°. **2.** 0.07 ([12]). **3.** 0.01 ([12]). **4.** 0.007 ([12]). **5.** 0.0033 ([12]). **6.** NO is colorless gas readily transformed into brown NO_2 by atmospheric oxygen. **7.** As gas, through respiratory organs. **8.** Local cauterization of the respiratory tract, leading to laryngitis, bronchitis, hyperemia, hemorrhages and severe edema in addition to vicarious emphysema of the lungs. In men the real illness generally appears only 4 to 6 hours or more after inhalation of the gas; in animals lung edema and a condition threatening to be dangerous ensue promptly ([12]). **9.** Manufacture of aniline, artificial leather, celluloid, dimethyl sulfate, explosives, felt hats, fertilizer, imitation pearls, incandescent lamps, picric acid, soda; dipping, mixing, recovering, transporting acid; bleaching, cartridge dipping, dipping and wringing gun-cotton, enamelling, etching, fur preparing, galvanizing, lithography, mining, nitrating, photo-engraving, pickling, metal refining, steel engraving; work with glue, jewelry, mordants, nitric acid, nitroglycerin, sulfuric acid.

Nitrobenzene, $C_6H_5NO_2$.—**1.** 210.9°. **4.** 0.0001 ([3]). **5.** 0.00002 ([3]). **6.** Colorless, highly refractive fluid having an odor like that of bitter almonds. (All nitro-compounds of benzene have similar properties). **7.** As gas, through the respiratory organs. **8.** Methemoglobin formation, general debility, anemia, presence of free hematoporphyrin, albumin, and sometimes free poison in the urine; jaundice, gradually becoming cyanosis; skin eruptions, visual disturbances, dyspnea, odor of bitter almonds in breath. **9.** Manufacture of aniline, dyes, explosives, perfumes, smokeless powder, soap.

Phosgene, $COCl_2$.—**1.** 8.2°. **2.** 0.02–0.05 ([2]). **3.** 0.0025 ([2]). **5.** 0.0001 ([2]). **6.** Colorless gas of suffocating odor. **7.** As vapor, through the respiratory organs. **8.** Destruction of lung tissue, emphysema and edema, myocardial insufficiency due to the emphysema, pleural thickening and adhesions, chronic bronchitis, mild diffuse bronchiectasis, nocturnal dyspnea, polycythemia. **9.** Manufacture of dyes, phosgene.

Phosphorus Trichloride, PCl_3.—**1.** 76°. **2.** 0.00035 ([3]). **3.** 0.00003–0.00005 ([3]). **4.** 0.000001–0.000002 ([3]). **5.** 0.0000004 ([3]). **6.** Liquid with sharp smell, fuming in air, and decomposing into phosphorous acid and hydrochloric acid ([13]). **7.** As vapor, through the respiratory organs. **8.** Sensation of suffocation, difficulty of breathing, lachrymation, bronchitis, edema and inflammation of the lungs, with frothy, blood-stained expectoration. **9.** Manufacture of phosphorus trichloride and organic compounds; use of phosphorus trichloride as chlorinating agent and as solvent of phosphorus.

Phosphine, PH_3.—**1.** −85°. **2.** 0.2 ([14]). **3.** 0.04–0.06 ([3]). **4.** 0.01–0.02 ([3]). **6.** Colorless gas of nauseating odor. **7.** As gas, through the respiratory organs. **8.** Oppressed feeling in the chest, headache, vertigo, tinnitus aurium, general debility, loss of appetite, great thirst. **9.** Manufacture of acetylene, red phosphorus; phosphorus extracting, work with ferro-silicon.

Sulfur Dioxide, SO_2.—**1.** −10°. **2.** 0.2 ([2]). **5.** 0.01 ([2]) **6.** Gas with pungent odor and suffocating effect. **7.** As gas, through the respiratory organs. **8.** Irritation of the mucous membrane of the respiratory organs and eyes, spasmodic cough, bronchial catarrh, digestive disturbances, blood-tinged mucus. **9.** Manufacture of alkali salts, bricks, brooms, carbolic acid; work around blast furnaces, brass foundries, sulfuric acid towers; bleaching, zinc charging.

Sulfur Trioxide, SO_3.—**2.** 0.001 ([2]). **5.** 0.0002 ([2]). **6.** White solid, which evolves dense white fumes on exposure to the air. **7.** As gas, through the respiratory organs. **8.** Irritation of the respiratory organs, bronchitis. **9.** Manufacture of sulfuric acid.

Toluidine, $CH_3C_6H_4NH_2$.—**1.** 200°. **4.** 0.00025 ([3]). **5.** 0.0001–0.00025 ([3]). **6.** Reddish brown liquid. **7.** As vapor, through the respiratory organs. **8.** Headache, weakness, difficulty in breathing, cyanosis, convulsions, psychical disturbances, air hunger, marked irritation of the renal organs ([13]). **9.** Manufacture of aniline, coal-tar dyes; tank and still work ([13]).

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(For a key to the periodicals see end of volume)

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PREVENTION AND EMERGENCY TREATMENT OF GAS POISONING

I. Prevention of poisoning
- A. For all gases
  1. Prevention of escape of vapor or fumes into the air of working places.
  2. Good ventilation.
  3. Testing before entering air suspected of containing poisonous gases.
  4. Never entering or working alone in places where the air is known to be contaminated by poisonous gases.
  5. Wearing of respirators, gas masks, hose masks, or oxygen breathing apparatus—the latter especially if the air is low in oxygen.
  6. Education of workmen regarding the danger of poisoning and methods of prevention.
- B. For special gases
  1. Protection of the skin by suitable clothing and by the application of oils, etc.

     In the case of dichlorodiethyl sulfide (mustard gas), ordinary clothing affords no protection, but cloth painted with linseed oil is adequate. Oiling the skin gives some protection from short exposure to low concentrations of this gas and in high concentrations increases the efficiency of removal-treatment; for long exposure, oils give practically no protection.
  2. Abstinence from alcohol, at least during and immediately after labor, especially when exposed to such gases as aniline, toluidine, and nitrobenzene.
  3. Scrupulous cleanliness of working places and personally on the part of the workmen.
  4. Physical examination of prospective employees to see that they are not suffering from any disease that would make them more susceptible to certain poisonous gases; reexamination of employees at stated intervals (every 30 days for workers in aniline) to detect beginning of poisoning, especially where exposed to fumes of aniline, mercury, and other gases, the action of which is cumulative and danger of acute poisoning is not so great.

II. Emergency treatment
- A. For all gases
  1. Immediate removal from poisonous atmosphere to fresh air.
  2. Immediate administration of artificial respiration (preferably by the Schaefer prone pressure method) if breathing has ceased.
  3. Calling a physician.
  4. Keeping the patient at rest, lying down (very important).
  5. Keeping the patient warm and stimulating circulation by rubbing limbs of patient.
- B. For special gases
  1. Administration of pure oxygen, especially in case of carbon monoxide poisoning.[1]
  2. Administration of stimulants: Black coffee, caffein, camphor, or ether in case of poisoning by aniline, hydrogen cyanide, hydrogen sulfide, phosphine, and toluidine; subcutaneous administration of atropine in poisoning by hydrogen chloride, hydrogen sulfide, and phosphine; hypodermic administration of morphine in poisoning by hydrogen cyanide; inhalation of chloroform in poisoning by phosgene; inhalation of ammonia vapor or soda spray in poisoning by hydrogen chloride, phosgene, phosphorus trichloride, and chloropicrin; infusion of alkaline solution in poisoning by arsine, bromine, iodine, and sulfur dioxide.
  3. Venesection is recommended in treatment of poisoning by bromine, chlorine, iodine, nitrogen oxides, phosgene, and chloropicrin, but must not be used after collapse has started.
  4. In the case of dichlorodiethyl sulfide (mustard gas) prevention is especially important as palliative measures are not very successful. The respiratory lesions may be treated by frequent spraying or instillation of a few drops of 1 % sodium bicarbonate, followed by liquid petrolatum and gargling of the throat with a weak Dakin's solution. The eyes should be kept clean by frequent irrigation with a saturated solution of boric acid or with 1 % sodium bicarbonate, followed by a few drops of oil. All clothing should be removed to the skin. Burns of the skin from the vapor should be treated with antiseptics and protected from any irritation. Irritant drugs, such as picric acid or mercuric chloride solutions, should not be applied.

[1] Five per cent carbon dioxide in oxygen, if available, may be administered in carbon monoxide poisoning.

AIR CONDITIONING
A. HYGROSCOPIC PROPERTIES OF INDUSTRIAL MATERIALS

D. C. Lindsay

Hygroscopic Moisture.—The moisture contained in a hygroscopic material in equilibrium with the relative humidity of the surrounding atmosphere. The moisture content of a hygroscopic material when in equilibrium depends upon the relative humidity of the surrounding atmosphere but varies widely with different materials. The moisture content also varies to a slight extent with different temperatures at the same humidity. Hygroscopic moisture in materials is in most industries termed "*regain*," and is expressed in parts of water per 100 parts of dry material.

Hygroscopic Properties of Materials.—The hygroscopic properties of materials vary widely from one another and even in the same material a wide variation is frequently observed, and is dependent upon the prior history of the material. The curves given below are based upon a critical study of available data. Qualitatively, they are correct and can be used where extreme accuracy is not required. Consistency in form will be noted in all cases. For the accurate determination of hygroscopic characteristics of materials, the use of insulated cabinets provided with air circulation and automatic instruments (10) for controlling temperature and humidity are recommended as being superior to the taking of such data, within a stagnant atmosphere, the moisture equilibrium of which is maintained by hygroscopic solutions such as sulfuric acid.

Electrostatic Condition of the Atmosphere—Electrical charges are dissipated at normal temperatures (18 to 30°C) at a relative humidity of 50% or above.

This is of extreme importance in textile mills and printing plants where the charged atmosphere prevalent during the winter causes bristling of the fibers and hampers operations.

The elimination of static by humidification has been successfully applied to reduce explosion hazards in munition plants and other explosive atmospheres.

Mildew Fungi.—These will thrive in relatively still atmosphere only at relative humidities above 75%.

Favorable Conditions of Temperature and Humidity Artificially Created and Maintained in Manufacturing Processes

Industry and product	Process	Temp., °C	Relative humidity, %
Cotton	Carding	20 to 23	50
	Combing	20 to 23	60–65
	Roving	20 to 23	50–60
	Spinning	20 to 23	60–65
	Spooling, twisting	20 to 23	65
	Warping	20 to 23	65
	Weaving	20 to 23	75–80
Wool	Carding	23 to 25	65–70
	Spinning	23 to 25	55–60
	Weaving	20 to 23	50–55
	Storage for shipping	20 to 23	55–60
Silk	Dressing	21 to 25	60–65
	Spinning	21 to 25	65–70
	Throwing	21 to 25	65–70
	Weaving	21 to 25	60–70
Confectionery	Chocolate enrobing	18	≯55
	Hard candy making	21	≯50
	Storage	− 1	≯70
		+15*	≯55
Tobacco	Softening	29	85
	Cigar and cigarette making	21 to 23	55–70
Printing	Lithographing	21	45
	Relief and offset	25	45
	Folding	25	65
	Binding	21	45
Baking	Dough fermentation	27	65
	Proofing	32 to 35	80–90
	Loaf cooling	21	65
Electrical cable	Winding insulation	≯40	≯ 5
Cellulose lacquers	Application	24	≯20
Munitions	Fuse loading	21	55
Cereals	Seal packing prepared, crisp cereals	23	45–50

* Divergence in practice.

LITERATURE

(For a key to the periodicals see end of volume)

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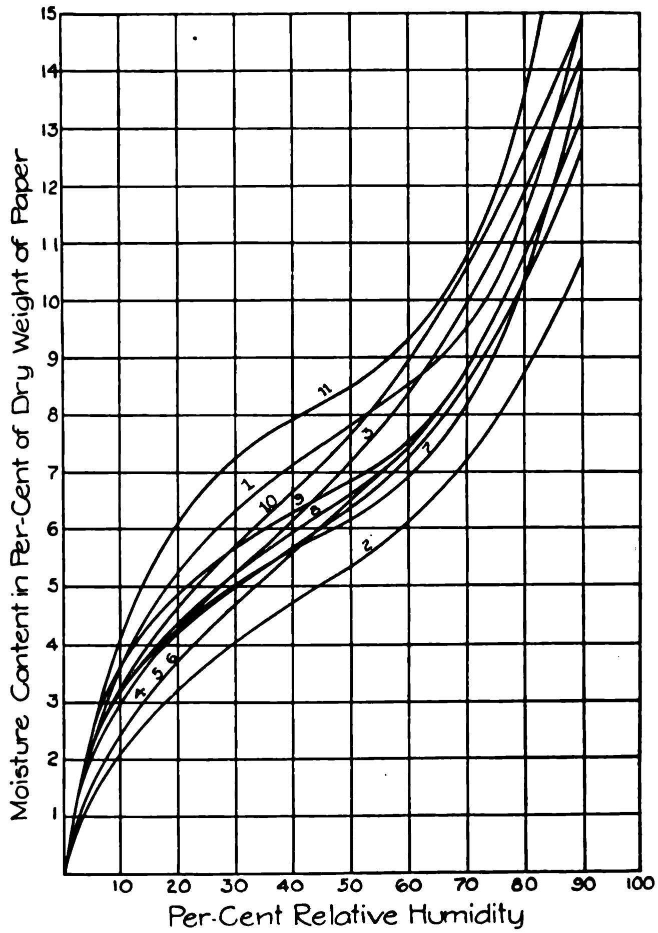


Fig. 1.—Hygroscopic moisture of various papers (*cf.* (2, 3, 6, 7, 11)).

Curve No.	Description	Ash, %	Rosin, %	Rag, %	Chemical wood bleached, %	Coniferous, %	Manila and jute, %	Lit.
1	Sulfite cellulose pulp							(3, 11)
2	News print	24.4	1.0		100			(6)
3	Writing	2.9	2.2		100			(6)
4	Fine white writing	0.8	1.2	100				(6, 7)
5	White bond	1.0	1.0	100				(6)
6	Fine white bond	0.2	1.0	100				(6)
7	Commercial ledger	0.6	1.7	75	25			(6)
8	White ledger	0.9	1.2	100				(6)
9	Index bristol	1.0	1.7	50	50			(6)
10	Kraft wrapping	0.3	1.3			100		(6)
11	Rope manila	1.6	1.5			25	75	(6)

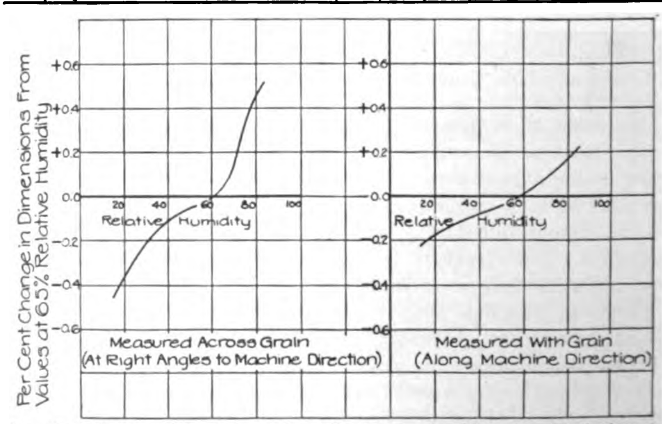


Fig. 2.—Composite curves for all papers in Fig. 1. Variation in dimensions with variation in relative humidity.

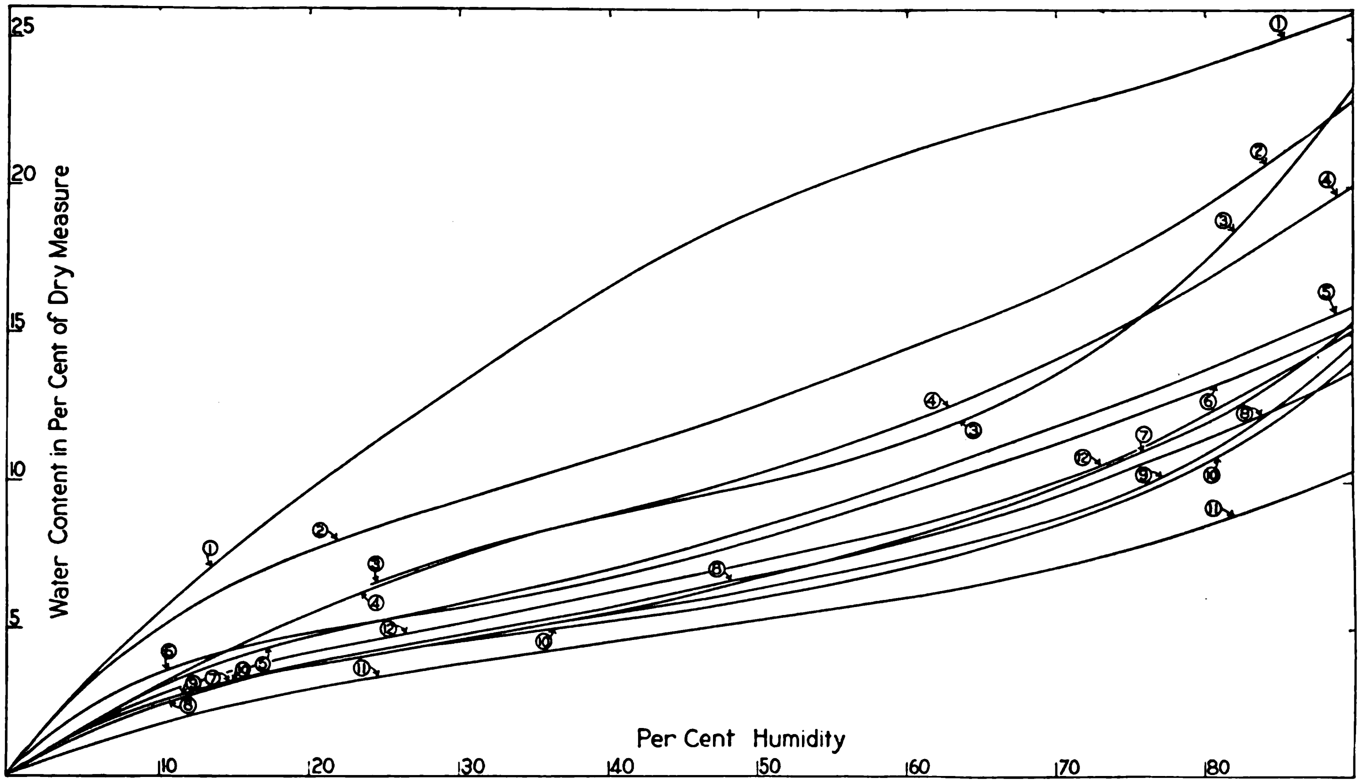


FIG. 3.—Hygroscopic moisture of natural fiber textile materials (3, 5, 12, 14).

Curve No.	Material	Curve No.	Material	Curve No.	Material	Curve No.	Material
1	Absorbent cotton	7	Indian cotton	4	Jute	10	American cotton
2	Wool, worsted	8	Cotton cloth	5	Manila hemp	11	Linen
3	Silk, new yellow	9	Egyptian cotton	6	Sisal hemp	12	Flax

All observations at approx. 25°C.

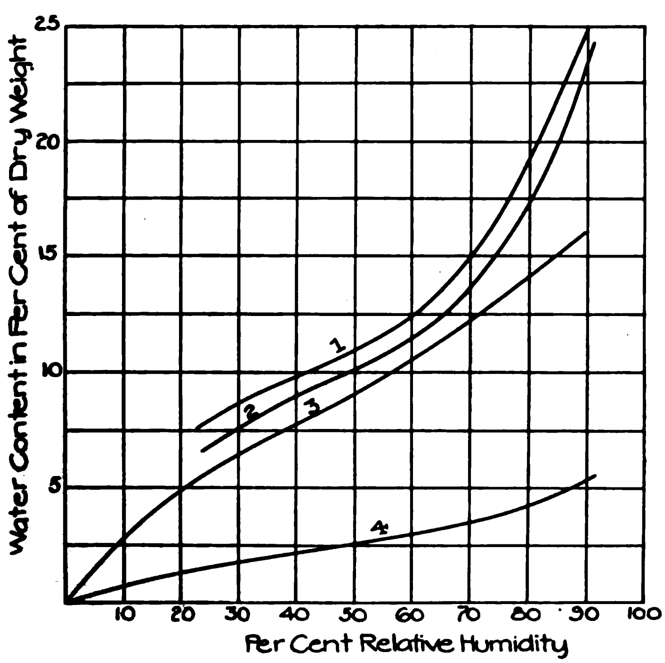


FIG. 4.—Hygroscopic moisture of artificial textile fibers compared with crude constituents and natural silk (3, 14).

Curve No.	Material
1	Viscose rayon (artificial silk)
2	Natural silk, new yellow
3	Nitrocellulose
4	Cellulose acetate

All observations at approx. 25°C.

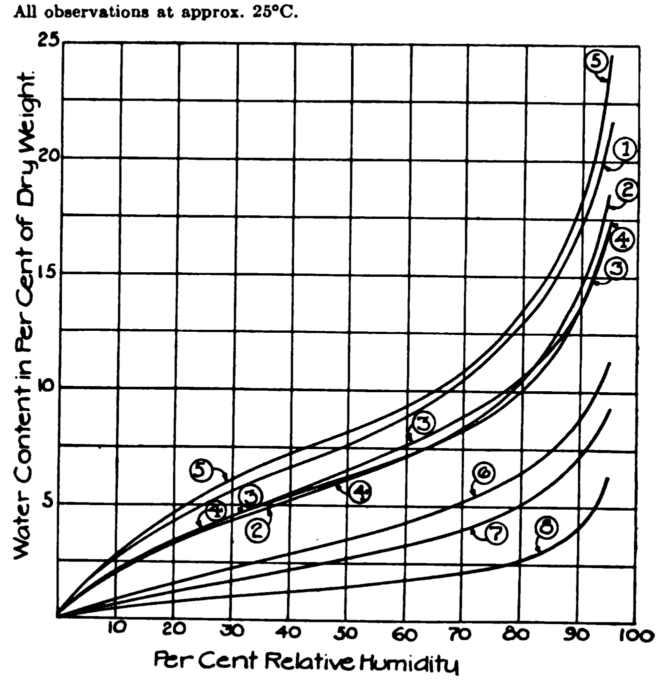


FIG. 6.—Hygroscopic moisture of various fibrous materials prepared for electrical insulation (8, 9).

Curve No.	Material
1	Manila paper
2	Red rope paper
3	Press board
4	Leatheroid paper
5	Silk
6	Red rope paper (varnished)
7	Empire cloth
8	Asbestos paper

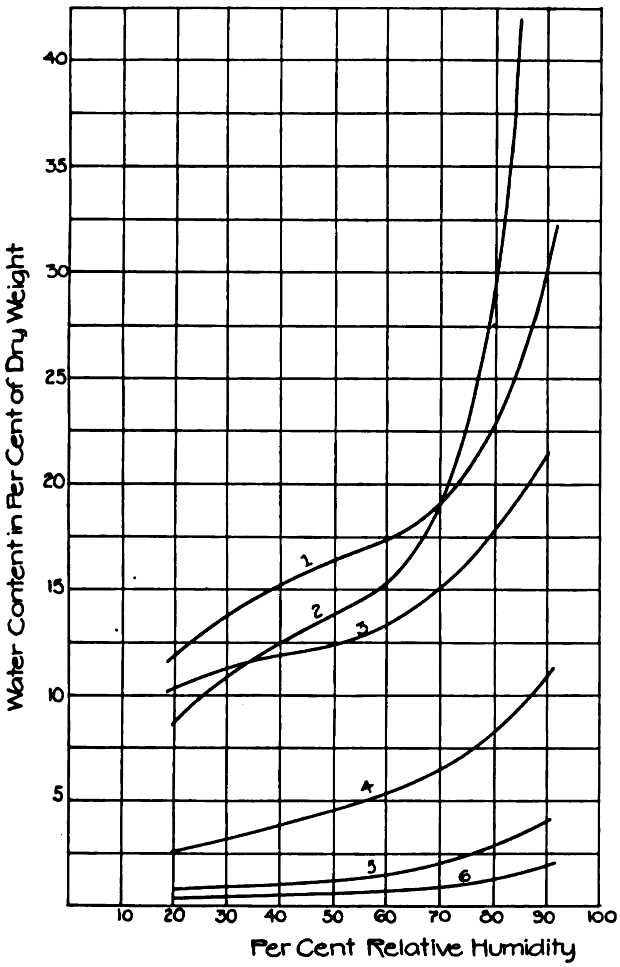


Fig. 5.—Hygroscopic moisture of leather and rubber ([3]).

Curve No.	Material
1	Leather (sole oak tanned)
2	Sheepskin
3	Gold beater skin
4	Latex, dipped cord
5	Reclaimed rubber
6	Smoked, crepe sheet

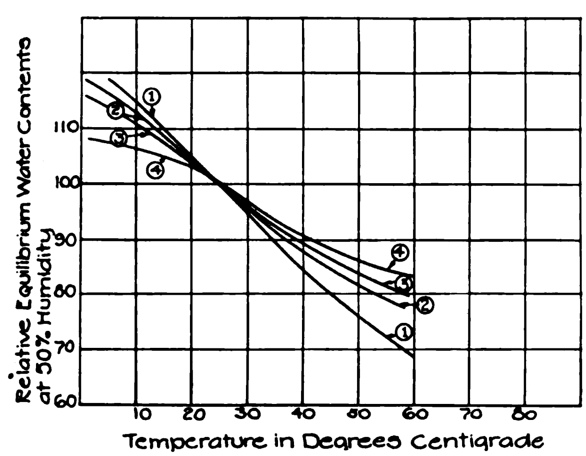


Fig. 11.—Effect of varying temperature on equilibrium water content at constant relative humidity of 50 % ([14]).

Curve No.	Material
1	Wood
2	Silk
3	Wool
4	Cotton

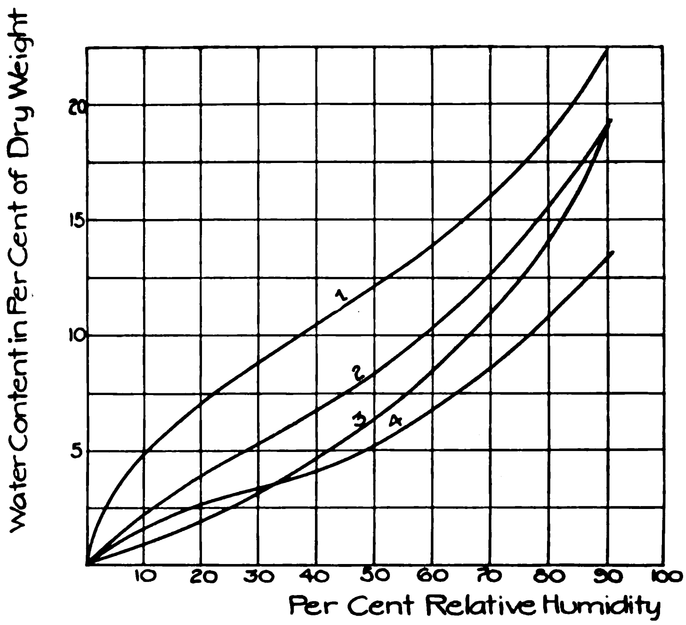


Fig. 7.—Hygroscopic moisture of cereal foods ([1, 3, 14]).

Curve No.	Material
1	Macaroni
2	Flour (patent)
3	Bread
4	Crackers

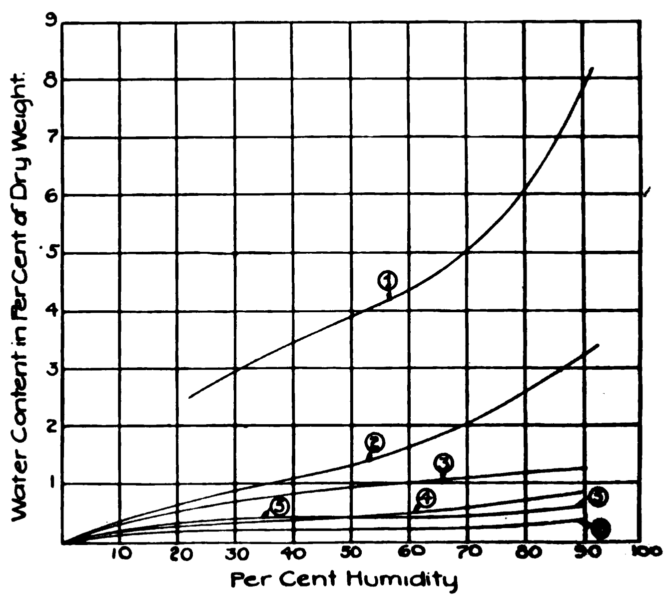


Fig. 8.—Hygroscopic moisture of some inorganic substances ([10, 14]).

Curve No.	Material
1	English ball clay
2	Kieselguhr
3	Kaolin
4	Asbestos fiber
5	Zinc oxide
6	Glass wool

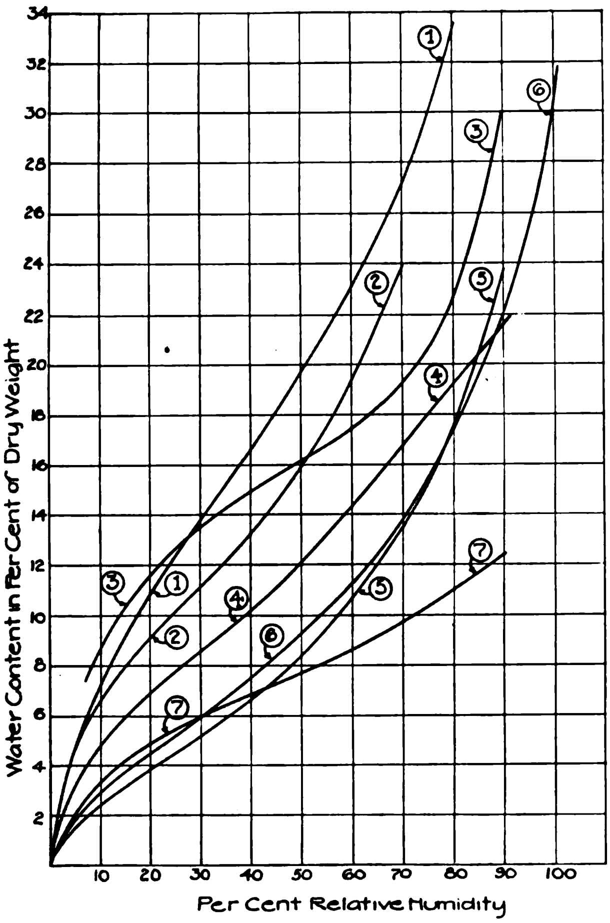


FIG. 9.—Hygroscopic moisture of some organic substances.

Curve No.	Material	Lit.
1	North Carolina leaf tobacco	(3)
2	Cigarette tobacco (Fatima)	(14)
3	Sole leather (oak tanned)	(3)
4	Catgut	(14)
5	Soap (Ivory)	(14)
6	Lumber*	(4)
7	Glue (hide, first grade)	(14)

* All species of timber have been found to have approximately the same values at given relative humidities. Rate of absorption or evaporation from timbers varies according to the density of the species.

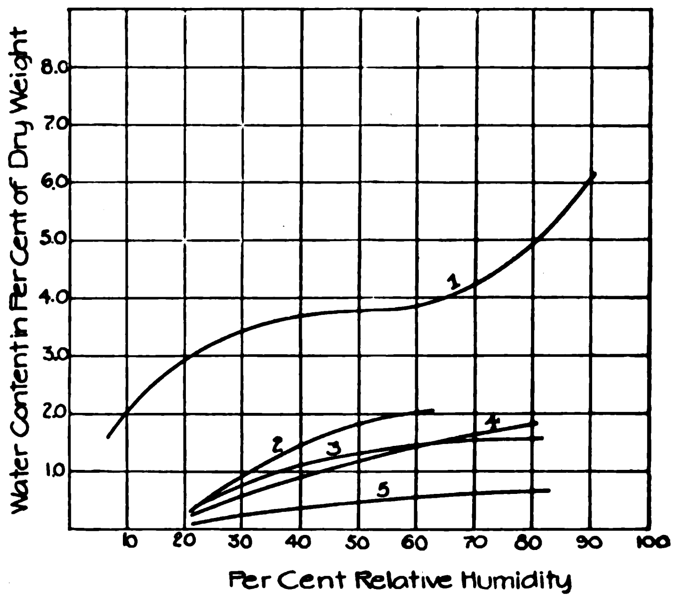


FIG. 10.—Hygroscopic moisture of carbon products (13, 14).

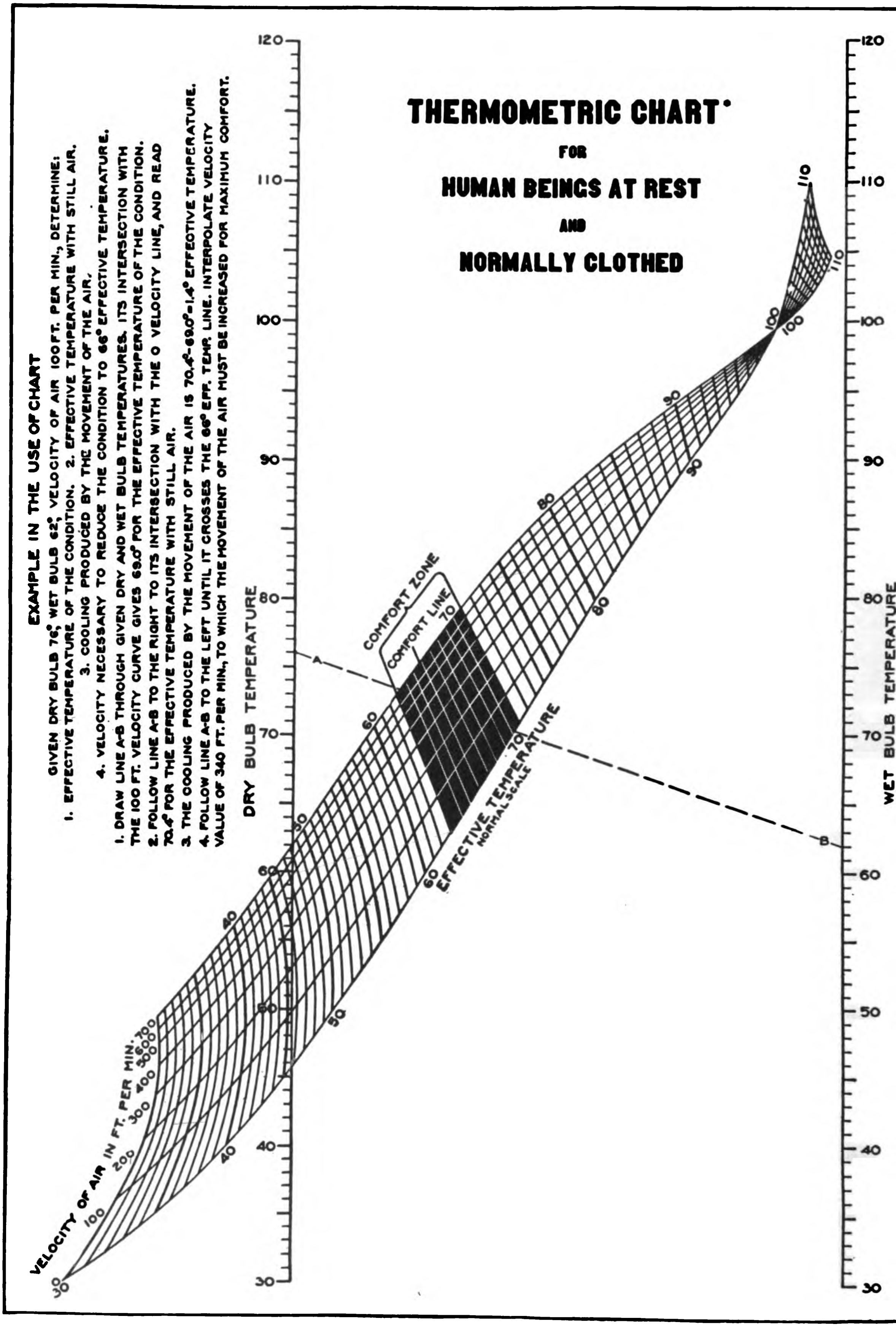
Curve No.	Material
1	Carbon black for rubber trade
2	By-product furnace coke (Franklin Co., Ill., coal)
3	By-product coke, domestic size (Pittsburgh bed coal)
4	By-product coke (domestic size)
5	Connellsville, 72 hour bee-hive foundry coke

B. SPACES OCCUPIED BY HUMAN BEINGS

R. R. SAYERS

EFFECTS OF TEMPERATURE AND HUMIDITY ON HUMAN BEINGS IN STILL AIR

Temperature of air, relative humidity 100%	Effects when at rest				Effects when at moderate work		
	Pulse rate	Body temperature	Metabolism	Remarks	Pulse rate	Body temperature	Remarks
°F 98	Greatly increased	Marked increase	Marked increase	Very hot, even with little clothing	Very rapid	Marked increase	Very hot
95	Marked increase	Increased	Increased	Hot, even when little clothing worn	Very rapid	Marked increase	Very hot
90	Increased	Increased	Increased	Very warm	Rapid	Increased	Hot
85	No change	No change	Slight increase	Warm	Increased	Slight increase	Very warm
75–80	Slight decrease	Slight decrease	Minimum metabolism	Comfortable	Slight increase	Slight increase	Comfortable or warm
65–70	Decrease	Slight decrease	Slight increase	Slightly cool to comfortable	Slight increase	Slight increase	Comfortable
55–60	Decrease	Slight decrease	Slight increase	Cool, clothing needed for comfort	Slight increase	Slight increase	Comfortable to cool
45–50	Decrease	Slight decrease	Increased	Cool, clothing needed for comfort	Slight increase	Slight increase	Cool



* *Jour. Am. Soc. of Heat. and Vent. Eng.*, **31**: 66; 25.

REFRIGERATING BRINES

R. S. Jessup

Aqueous Solutions.—All data are based upon weight *in vacuo*. p = wt. % anhyd. salt, t = °C, d = gram per milliliter, η = viscosity in centipoise, c = heat capacity under atmos. pressure.

For other data *see* sections of I. C. T. on the properties of salt solutions.

DENSITY AND SPECIFIC GRAVITY

Conversion Factors

1 g ml^{-1} = 0.999973 g cm^{-3} = 0.036126 lb. in.$^{-3}$ = 62.426 lb. ft.$^{-3}$ = 8.34523 lb. gal.$^{-1}$ (U. S.) = 10.0221 lb. gal.$^{-1}$ (Brit.).

Sodium Chloride, NaCl

d_4^{25} = sp. gr. = $[(0.99707 + 0.0070033p + 14.059 \times 10^{-6}p^2 + 330.9 \times 10^{-9}p^3) \pm 0.005\%]$ g ml^{-1}. Range, 5–25% [3, 4, 15, 20, 25].

$1/d_t = 1/d_0\,(1 + at + bt^2 - ct^3) \pm 0.005\ \%$ [20] whose values check those of [14, 27, 29, 30].

$d_4^t \pm < 0.01\ \%$.

p	−20°C	−10°C	0°C	10°C	20°C	30°C	a × 10⁴	b × 10⁶	c × 10⁹
5			1.03820	1.03659	1.03405	1.03074	1.0685	5.1425	21.750
6			1.04590	1.04403	1.04131	1.03786	1.3380	4.7100	19.000
7			1.05361	1.05150	1.04860	1.04503	1.5879	4.3162	16.547
8			1.06133	1.05900	1.05594	1.05225	1.8235	3.9350	14.000
9			1.06909	1.06654	1.06332	1.05951	2.0394	3.6062	12.047
10			1.07686	1.07411	1.07074	1.06682	2.2409	3.3037	10.297
11			1.08467	1.08173	1.07821	1.07417	2.4272	3.0362	8.875
12			1.09251	1.08939	1.08572	1.08158	2.6001	2.7962	7.703
13			1.10039	1.09709	1.09329	1.08904	2.7613	2.5725	6.578
14			1.10830	1.10483	1.10090	1.09656	2.9260	2.2575	3.750
15		1.11945	1.11626	1.11262	1.10857	1.10413	3.0629	2.0937	3.297
16		1.12765	1.12427	1.12047	1.11630	1.11177	3.1936	1.9187	2.453
17		1.13588	1.13232	1.12838	1.12409	1.11946	3.3127	1.7725	1.922
18		1.14415	1.14041	1.13634	1.13193	1.12722	3.4253	1.6300	1.328
19		1.15246	1.14857	1.14436	1.13984	1.13504	3.5290	1.5100	1.000
20		1.16082	1.15678	1.15244	1.14782	1.14293	3.6237	1.4125	0.922
21		1.16923	1.16505	1.16058	1.15586	1.15089	3.7129	1.3187	0.797
22		1.17770	1.17337	1.16880	1.16397	1.15891	3.7950	1.2375	0.750
23	1.19044	1.18622	1.18176	1.17707	1.17215	1.16702	3.8717	1.1337	
24		1.19480	1.19022	1.18542	1.18040	1.17519	3.9425	1.0675	
25			1.19874	1.19383	1.18873	1.18344	4.0090	1.0050	

Calcium Chloride, $CaCl_2$

d_4^0 = sp. gr. = $[(0.99987 + 0.0086417p + 29.17 \times 10^{-6}p^2 + 321.3 \times 10^{-9}p^3) \pm 0.03\%]$ g ml^{-1} [6].

$d_t = (d_0 - at - bt^2) \pm 0.05\%$ [23.5].

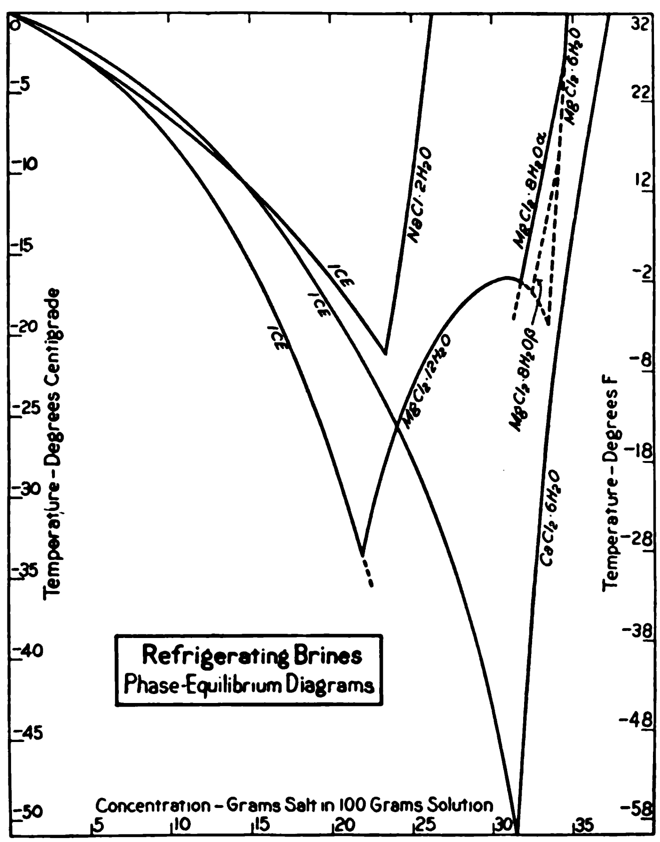
p	−30°	−20°	−10°	0°	10°	20°	30°	a × 10⁶	b × 10⁶
5				1.0438	1.0425	1.0402	1.0369	80	5.0
6				1.0528	1.0513	1.0489	1.0456	105	4.5
7				1.0619	1.0602	1.0577	1.0544	130	4.0
8				1.0710	1.0691	1.0664	1.0629	150	4.0
9				1.0802	1.0781	1.0753	1.0718	175	3.5
10				1.0895	1.0872	1.0843	1.0808	200	3.0
11				1.0989	1.0964	1.0934	1.0899	225	2.5
12				1.1083	1.1056	1.1025	1.0993	250	2.0
13				1.1178	1.1150	1.1117	1.1079	255	2.5
14				1.1274	1.1244	1.1210	1.1172	280	2.0
15			1.1396	1.1371	1.1340	1.1304	1.1261	278	2.8
16			1.1496	1.1469	1.1438	1.1399	1.1357	297	2.6
17			1.1597	1.1568	1.1534	1.1495	1.1451	315	2.5
18			1.1698	1.1667	1.1632	1.1592	1.1548	332	2.2
19			1.1801	1.1768	1.1731	1.1690	1.1645	350	2.0
20			1.1904	1.1869	1.1831	1.1788	1.1742	368	1.8
21		1.2046	1.2010	1.1972	1.1932	1.1889	1.1844	392	1.2
22		1.2150	1.2114	1.2075	1.2033	1.1989	1.1942	403	1.3
23		1.2260	1.2221	1.2180	1.2137	1.2092	1.2045	420	1.0
24		1.2369	1.2328	1.2285	1.2240	1.2194	1.2146	438	0.8
25		1.2481	1.2437	1.2392	1.2346	1.2299	1.2251	455	0.5
26	1.2634	1.2590	1.2545	1.2499	1.2452	1.2403	1.2354	467	0.6
27	1.2749	1.2703	1.2656	1.2608	1.2559	1.2510	1.2460	483	0.4
28	1.2868	1.2818	1.2768	1.2718	1.2668	1.2617	1.2567	502	0.1
29	1.2981	1.2930	1.2879	1.2828	1.2777	1.2725	1.2674	512	0.1
30	1.3098	1.3045	1.2993	1.2940	1.2888	1.2835	1.2783	525	0

Magnesium Chloride, $MgCl_2$

d_4^0 = sp. gr. = $[(0.99987 + 0.008652p + 16.26 \times 10^{-6}p^2 + 487.7p^3) \times 10^{-9} \pm 0.03\%]$ g ml^{-1} [6].

$d_t = (d_0 - at - bt^2) \pm 0.05\%$ [23.5].

p	−30°	−20°	−10°	0°	10°	20°	30°	a × 10⁶	b × 10⁶
5				1.0436	1.0426	1.0404	1.0372	50	5.5
6				1.0525	1.0513	1.0491	1.0459	70	5.0
7				1.0614	1.0600	1.0577	1.0545	95	4.5
8				1.0704	1.0689	1.0665	1.0633	105	4.5
9				1.0794	1.0778	1.0753	1.0719	115	4.5
10				1.0885	1.0867	1.0842	1.0807	145	3.5
11				1.0977	1.0958	1.0932	1.0899	155	3.5
12			1.1083	1.1069	1.1049	1.1022	1.0989	172	3.1
13			1.1177	1.1162	1.1141	1.1114	1.1081	180	3.0
14			1.1272	1.1255	1.1233	1.1205	1.1173	197	2.6
15			1.1368	1.1350	1.1327	1.1299	1.1266	205	2.5
16			1.1465	1.1445	1.1421	1.1392	1.1360	222	2.1
17			1.1561	1.1540	1.1515	1.1486	1.1453	230	2.0
18		1.1677	1.1659	1.1637	1.1611	1.1582	1.1549	238	1.8
19		1.1778	1.1758	1.1735	1.1709	1.1679	1.1647	247	1.6
20		1.1878	1.1857	1.1833	1.1806	1.1776	1.1743	255	1.5
21	1.1995	1.1977	1.1956	1.1932	1.1905	1.1874	1.1840	258	1.6
22	1.2099	1.2080	1.2058	1.2033	1.2005	1.1974	1.1940	264	1.5
23		1.2186	1.2161	1.2134	1.2105	1.2074	1.2041	280	1.0
24		1.2289	1.2263	1.2236	1.2206	1.2175	1.2142	285	1.0
25		1.2393	1.2367	1.2339	1.2310	1.2278	1.2245	288	0.8
26		1.2500	1.2473	1.2444	1.2413	1.2381	1.2347	298	0.8
27			1.2578	1.2549	1.2518	1.2486	1.2452	298	0.8
28			1.2686	1.2656	1.2625	1.2592	1.2558	307	0.7
29			1.2794	1.2763	1.2731	1.2698	1.2664	315	0.5
30			1.2903	1.2872	1.2840	1.2807	1.2773	315	0.5



HEAT CAPACITY (SPECIFIC HEAT)

Conversion Factors

1 joule g^{-1} per °C = 0.2389 g-cal_{15} g^{-1} per °C or BTU_{60} $lb.^{-1}$ per °F
= 2.778 × 10^{-7} kw-hr g^{-1} per °C
1 joule cm^{-3} per °C = 1.994 BTU_{60} $gal.^{-1}$ per °F (U. S.)
= 2.394 BTU_{60} $gal.^{-1}$ per °F (Brit.)

Sodium Chloride, NaCl

$c_{20} = [0.6516 + (0.3475)(0.96285)^p]$ cal_{15} g^{-1} per °C; $c_t = [c_{20} + a(t - 20) - b(t - 20)^2]$ cal_{15} g^{-1} per °C (2).

p	Joule per gram per °C ± 0.1 % −10°	0°	10°	20°	30°	a×10⁴	b×10⁶
5		3.911	3.921	3.931	3.940	2.3	0
6		3.862	3.874	3.886	3.896	2.6	−1
7		3.816	3.830	3.843	3.854	2.8	−2
8		3.771	3.787	3.801	3.813	3.0	−3
9		3.730	3.747	3.761	3.772	3.0	−4
10		3.689	3.708	3.723	3.734	3.1	−5
11		3.651	3.670	3.686	3.697	3.2	−5
12		3.615	3.635	3.650	3.661	3.2	−5
13		3.580	3.600	3.615	3.627	3.2	−5
14		3.547	3.567	3.583	3.593	3.1	−6
15	3.491	3.516	3.536	3.551	3.561	3.0	−6
16	3.463	3.487	3.506	3.520	3.530	2.8	−6
17	3.435	3.458	3.477	3.491	3.500	2.7	−6
18	3.409	3.432	3.450	3.463	3.471	2.5	−6
19	3.384	3.406	3.423	3.435	3.443	2.3	−6
20	3.361	3.382	3.398	3.409	3.415	2.0	−6
21	3.338	3.358	3.374	3.384	3.389	1.8	−6
22	3.318	3.337	3.351	3.359	3.363	1.5	−6
23*	3.298	3.315	3.328	3.336	3.340	1.5	−5
24	3.279	3.295	3.306	3.313	3.316	1.2	−5
25	3.261	3.276	3.286	3.292	3.293	0.9	−5

* For p = 23; c = 3.277 at −20°.

Calcium Chloride, $CaCl_2$

$c_0 = [(1.0138 - 0.018091p + 197.34 \times 10^{-6}p^2) + 0.002]$ cal_{15} g^{-1} per °C (10).

$c_t = (c_0 + at + bt^2) \pm 0.002$ cal_{15} g^{-1} per °C.

p	Joule per gram per °C −40°	−30°	−20°	−10°	0°	10°	20°	30°	a×10⁴	b×10⁶
8					3.691	3.712	3.733	3.754	5.0	0
9					3.628	3.649	3.670	3.691	5.0	0
10					3.570	3.591	3.612	3.633	5.2	0
11					3.511	3.532	3.553	3.578	5.4	0
12					3.453	3.478	3.500	3.524	5.5	0
13					3.398	3.423	3.444	3.469	5.7	0
14					3.344	3.369	3.393	3.419	5.9	0
15					3.294	3.319	3.344	3.369	6.0	0
16				3.214	3.243	3.268	3.294	3.315	6.8	−4
17				3.164	3.193	3.222	3.243	3.264	6.9	−4
18				3.118	3.147	3.176	3.197	3.218	7.0	−4
19				3.072	3.101	3.130	3.155	3.176	7.1	−4
20				3.026	3.059	3.089	3.114	3.135	7.1	−4
21				2.984	3.017	3.047	3.068	3.093	7.2	−4
22			2.909	2.946	2.976	3.005	3.030	3.051	7.3	−4
23			2.871	2.904	2.938	2.967	2.992	3.017	7.4	−4
24			2.837	2.871	2.900	2.930	2.955	2.980	7.2	−3
25			2.804	2.837	2.867	2.896	2.921	2.946	7.0	−2
26		2.745	2.775	2.804	2.833	2.858	2.888	2.912	6.7	−1
27		2.716	2.745	2.775	2.800	2.829	2.854	2.883	6.6	0
28	2.662	2.687	2.716	2.745	2.770	2.800	2.825	2.854	6.5	0
29	2.653	2.674	2.695	2.716	2.741	2.770	2.796	2.825	6.0	2
30	2.641	2.657	2.670	2.691	2.716	2.741	2.766	2.796	5.7	3

Magnesium Chloride, $MgCl_2$

$c_0 = [(1.00070 - 0.016746p + 144.9 \times 10^{-6}p^2) \pm 1\%]$ cal_{15} g^{-1} per °C (23). $c_t = (c_0 + at)$ cal_{15} g^{-1} per °C (23).

Magnesium Chloride, $MgCl_2$.—(*Continued*)

p	Joule per gram per °C −30°	−20°	−10°	0°	10°	20°	30°	a×10⁴
5				3.879	3.888	3.896	3.905	1.9
6				3.817	3.825	3.838	3.846	2.4
7				3.754	3.767	3.779	3.787	2.8
8				3.691	3.704	3.720	3.733	3.3
9				3.633	3.649	3.662	3.679	3.7
10				3.574	3.591	3.607	3.624	4.1
11				3.515	3.536	3.553	3.573	4.5
12			3.440	3.461	3.482	3.503	3.520	4.8
13			3.386	3.407	3.428	3.448	3.474	5.2
14			3.327	3.352	3.373	3.398	3.419	5.5
15			3.273	3.297	3.323	3.348	3.369	5.8
16		3.197	3.222	3.248	3.273	3.297	3.323	6.0
17		3.147	3.172	3.197	3.222	3.248	3.277	6.2
18		3.093	3.122	3.147	3.172	3.202	3.227	6.3
19		3.047	3.076	3.101	3.126	3.155	3.181	6.4
20	2.976	3.001	3.030	3.055	3.084	3.109	3.139	6.5
21	2.930	2.955	2.984	3.009	3.038	3.063	3.093	6.5
22		2.912	2.938	2.967	2.992	3.022	3.047	6.5
23		2.871	2.896	2.921	2.950	2.976	3.005	6.5
24		2.829	2.854	2.883	2.909	2.938	2.963	6.5
25		2.787	2.817	2.842	2.867	2.896	2.921	6.4
26		2.750	2.779	2.804	2.829	2.858	2.883	6.4
27		2.708	2.737	2.762	2.787	2.817	2.842	6.3
28			2.699	2.729	2.754	2.779	2.808	6.2
29			2.666	2.691	2.716	2.741	2.766	6.1
30			2.632	2.657	2.683	2.708	2.733	6.0

VISCOSITY

Data for low temperatures, very meager. The information available is expressed by the following equations and tables: (*cf.* I. C. T. sections on viscosity of H_2O and salt solutions).

NaCl, $\eta = [(\eta_w + ap + bp^2) \pm 0.5\%]$. Range, 0–30° and 5–20% (18, 19, 32, 37).

$CaCl_2$, $\log \eta = [(\log \eta_w + ap + bp^2) \pm 3\%]$. Range 10–30°, 5–30% (37).

For p = 30.89%, $\eta = [(0.139_2 + 0.00481_5 t + 47.2_7 \times 10^{-6}t^2) \pm 5\text{–}10\%?]$. Range, −50 to 30° (39).

$MgCl_2$, $\eta_{25°} = 0.895 + 0.0339p + 900 \times 10^{-6}p^2 + 82.14 \times 10^{-6}p^3$. Range 0–22%. Precision ±0.5%. Accuracy ? (18, 41).

		0°	5°	10°	15°	20°	25°	30°
$CaCl_2$	a×10³ =			113.94	54.61	0	−47.69	−95.83
	b×10³ =			6.0996	6.4427	6.8451	7.0553	7.6747
	c×10⁶ =			380.50	381.31	375.85	370.27	352.68
21.56%	η =		3.113(17)	2.729(17)	2.412(17)			
NaCl	a×10³ =	4.90	9.20	10.65	10.90	10.70	10.20	9.75
	b×10³ =	1.930	1.410	1.125	0.930	0.790	0.690	0.605
0%	η_w =	1.794	1.519	1.310	1.145	1.009	0.895	0.800
20%	η =	2.663	2.269	1.973	1.733	1.538	1.376	1.249

LITERATURE

(For a key to the periodicals see end of volume)

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SIEVES AND SCREENS

LEWIS V. JUDSON

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INHALTSVERZEICHNIS

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INTRODUCTION

The accuracy of woven metal sieves is often very high. An idea of the accuracy which may reasonably be expected in precision testing sieves may be obtained from the data in Table 2. For many purposes, such a narrow tolerance is not necessary and should not be required. An abnormally wide separation between two adjacent parallel wires may cause a serious error, especially in sieves with narrow openings. In bolting cloth, the diameters of the threads and the widths of the openings vary, not only from brand to brand, but even from bolt to bolt of the same brand. When accuracy is required, it is necessary to select particular portions of selected bolts of the cloth. Sieves are commonly designated either by the mesh per unit of length, or by the mesh per unit of area. Several different units of length (and of area) are employed. For U. S. A. grain sieves, *see* following publications of the U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

INTRODUCTION

La précision des tamis métalliques tissés est souvent très grande. On peut se faire une idée de la précision qui peut être raisonablement attendue des tamis pour essais de précision, en consultant les données de la Table 2. Pour beaucoup de buts, une tolérance aussi étroite n'est pas nécessaire et ne doit pas être exigée. Une séparation anormalement large entre deux fils adjacents parallèles peut occasionner une sérieuse erreur spécialement dans les tamis à réseaux fins. Dans les étamines, les diamètres des fils et la largeur des ouvertures varient, non seulement de marques à marques, mais aussi souvent d'étamines à étamines de la même marque. Lorsqu'on exige de la précision, il est nécessaire de choisir des portions particulières d'étamines choisies. Les tamis sont communément désignés ou par le nombre de mailles par unité de longueur, ou par le nombre de mailles par unité de surface. On emploie plusieurs unités de longueur (et de surface) différentes. Pour les tamis de grains des États Unis, voir les publications suivantes du Département d'Agriculture des États Unis: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

EINLEITUNG

Gewebte Metallsiebe haben häufig einen hohen Grad von Genauigkeit. Eine Vorstellung davon, wieweit sich diese bei der Präzision der Prüfung treiben lässt, erhält man aus den Angaben der Tafel 2. Für viele Zwecke ist eine so kleine Toleranz nicht notwendig und soll auch nicht gefordert werden. Eine abnormal grosse Entfernung zwischen zwei benachbarten parallelen Drähten, kann Ursache grösserer Fehler werden, besonders bei Sieben mit engen Öffnungen. Bei Siebtüchern ändert sich der Durchmesser der Fäden und die Öffnungsweite nicht nur von Marke zu Marke, sondern sogar in den Tüchern derselben Marke. Ist hier Genauigkeit gefordert, so ist es notwendig, gewisse Teile der gewählten Tücher auszusondern. Siebe sind im allgemeinen entweder durch die Zahl der Maschen pro Längen- oder pro Flächeneinheit gekennzeichnet. Es sind einige verschiedene Längen- und Flächenmasse üblich. Für die Siebe (Korn, etc.) der Vereinigten Staaten siehe die folgenden Abhandlungen des U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) (Korn Standard); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-No. 142) (Sandzucker); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) (Mühlen Reis); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

INTRODUZIONE

Gli stacci di tessuto metallico hanno spesso un alto grado di esattezza. Una idea della approssimazione che può ragionevolmente attendersi con stacci per saggi di precisione, può dedursi dai dati della Tabella 2. Per molti scopi una tolleranza così stretta non è necessaria, e non potrebbe pretendersi. Una distanza anormalmente grande fra due fili paralleli adiacenti può essere causa di gravi errori, specialmente negli stacci a fori piccoli. Nelle tele da buratti, il diametro dei fili e l'ampiezza dei fori variano non solo da marca a marca, ma anche nei tessuti di una stessa marca. Se si richiede grande esattezza è necessario scegliere particolari porzioni di tessuti scelti. Gli stacci sono in genere designati in base al numero di maglie per unità di lunghezza o di superficie. Le unità adoperate sono differenti.

Per gli stacci da granaglie degli S. U. A. vedi le pubblicazioni seguenti del U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

Table 1.—Series of Woven Sieves

For pharmaceutical sieves, *see* Table 3

D = diameter of wire (mm); O = width of opening (mm).

Sieve designation[a]	United States of America						Great Britain	France			Switzerland
	U. S. Standard[b]		Tyler[c, d] Standard screen scale	Howard[d, e] and Morse sieve series (old)	Newark[d, e] "Market Grade" testing sieves		Institute[d, f] Mining and Metallurgy; Standard screens	Suter-Strehler[g] sieve series	Weiller and Cie.	Franck and Cie.	Market[h] Grade testing sieve cloth
N	D	O	O	O	O		O	O			O
			*26.67						Designated by number of meshes per 27.777 mm; *cf.* preceding column. Sieves of the same designation are woven with wires of various sizes, and O varies accordingly: for example, the catalogue lists No. 20 sieve in 14 different sizes of wire.	Designated by number of meshes per 27 mm; for approximate size of openings, *see* following column.	
			22.43								
			*18.85								
			15.85								
			*13.33								
			11.20								
2			* 9.423					12.1			12
2½			7.925					9.5			9.5
3			* 6.680					8.1			7.8
3½			5.613								
4	1.27	4.76	* 4.699	5.11				5.94			5.8
5	1.12	4.00	3.962				2.540	4.66			4.5
6	1.02	3.36	* 3.327	3.33				3.83			3.7
7	0.92	2.83	2.794					3.27			3.2
8	0.84	2.38	* 2.362	2.43			1.574	2.77			2.7
9			1.981								2.4
10	0.76	2.00	* 1.651	1.86			1.270	2.18			2.1
11											1.9
12	0.69	1.68	1.397	1.49			1.056	1.81			1.75
14	0.61	1.41	* 1.168	1.23				1.54			1.45
15											1.35
16	0.54	1.19	0.991	1.07			0.792	1.34			1.30
18	0.48	1.00		0.93				1.14			1 10
20	0.42	0.84	* 0.833	0.85	0.864		0.635	1.03			0.95
22½											0.87
24			0.701	0.71							
25	0.37	0.71						0.75			0.76
27½											0.66
28			* 0.589								
30	0.33	0.59		0.54	0.516		0.421	0.65			0.62
32			0.495								
35	0.29	0.50	* 0.417	0.44				0.55			0.53
40	0.25	0.42		0.38	0.381		0.317	0.494			0.47
42			0.351								
45	0.22	0.35									
48			* 0.295								
50	0.188	0.297		0.28	0.279		0.254	0.376			
60	0.162	0.250	0.246	0.23	0.234		0.211	0.30			
65			* 0.208								
70	0.140	0.210		0.20	0.185		0.180	0.26			
80	0.119	0.177	0.175	0.174	0.173		0.157	0.227			
90				0.155	0.155		0.139	0.209			
100	0.102	0.149	* 0.147	0.142	0.140		0.127	0.178			
110				0.127	0.130						
115			0.124								
120	0.086	0.125		0.117	0.117		0.107	0.151			
130				0.104	0.109			0.134			
140	0.074	0.105		0.100	0.107			0.128			
150			* 0.104	0.091	0.104		0.084	0.125			
160				0.088	0.097						
170	0.063	0.088	0.088	0.083	0.089						
180				0.079	0.084			0.094			
190				0.079	0.079						
200	0.053	0.074	* 0.074	0.071	0.074		0.063	0.089			
230	0.046	0.062			0.065						
250			0.061		0.061						
270	0.041	0.053	0.053		0.053						
300					0.046						
325	0.036	0.044	0.043		0.043						

[a] Sieve designation is number of meshes per linear unit. For U. S. and Great Britain the unit is the inch (= 25.4 mm), excepting for the U. S. Standard, for which the unit varies slightly but always approximates closely to the inch; for the Suter-Strehler series it is 27.8 mm: and for Switzerland it is 27 mm.

[b] Specifications require a frame 8 in. in diameter (3 in. for paint pigments), and either 5 cm or 2.5 cm high (above cloth). For tolerances, *see* Table 2. This series has been tentatively adopted, as standard, by the American Society for Testing Materials, using a preferred designation of width of opening in microns. Sieves of this series now used by most A. S. T. M. committees, and specifications requiring other series, are in process of revision.

[c] Widths of openings in successive sieves are related as 1 to $\sqrt[4]{2}(=1.189)$: those starred (*), as 1 to $\sqrt{2}(=1.414)$. The scale is based upon the No. 200 sieve with openings 0.0029 in. wide. Successive sieves finer than No. 4 nominally correspond, within limits of tolerance, with successive sieves of the U. S. Standard series, but there are notable differences in the designations of the two series.

[d] $D + O = 25.4/N$.

[e] U. S. Standard is now regular with Howard and Morse, Inc., but the Old Howard and Morse Standard is obtainable.

[f] This series is the standard of British Engineering Standards Committee.

[g] $D + O = 27.8/N$.

[h] $D + O = 27/N$.

Table 2.—Tolerances for U. S. Standard Sieves*

D = diameter of wire; O = width of opening; min. = minimum; max. = maximum; av. = average. Unit: 1% of specified value.

Sieves	O		D_{av}	
	Av.	Max.	Min.	Max.
4 to 18	±3	10	−15	+30
20 to 45	±5	25	−15	+30
50 to 120	±6	40	−15	+35
140 to 200	±8	60	−15	+35
230 to 325	±8	90	−15	+35

* *See* Table 1.

Example: For sieve No. 30 of U. S. Standard, the average diameter of the wire must be not more than 15 % smaller or 30 % greater than 0.33 mm (Table 1); the width of the average opening must not differ from 0.59 mm by more than ±5 % (= ±0.01 mm), and the width of the largest opening must not exceed 0.59 mm by more than 25 % (=0.15 mm).

Table 3.—Pharmaceutical Sieves

In the body of the table are indicated the sieves composing a complete set, and the customary designations of the several sieves: * indicates that the sieve is designated by the number of meshes per cm as given in first column (Italy is an exception: *see* note). "Width" = width of opening.

Meshes per cm	Width (mm)	Austria	Belgium	Denmark	Finland	France		Germany	Great Britain	Hungary	Italy[2]	Japan	Mexico	Netherlands[3, 4]	Norway	Russia	Sweden[6]	Switzerland[3]	U. S. A.
						Old[1]	New												
	8	I							Commercial sieves not specifically designated						1				Selected from U. S. Standard. Table 1
	6									I									
	5																		
2			*	*		5	I												
	4				I					II		1	1		2				
3			*	*		8	II												
	3	II			II							2	2						
	2	III			III					III		3	3		3				
5			*	*															
6						16	III												
	1.5																		
9						25	IV												
10		IV	*	*						IV	*	4	4	*	4	IV	No. 10		
	0.75				IV			4											
15						40	V											IV	
18																III			
20			*											*	5		No. 20		
22						60	VI												
25										V									
26		V				70	VII					5							
27																		V	
30			*	*		80	VIII				*			*	6		No. 30		
32													5			II			
	0.30				V			5											
37						100	IX											} VI	
40			*							VI	*	6		*	7	I	No. 40		
45						120	X												
48		} VI		*[6]									6	*					
50																			
51																		} VII[6]	
52						140	XI												
	0.15				VI			6											
70													7						
Grading[5]		*a*	*b*	*c*	*a*	*d*	*d*	*e*	*h*	*a*	*a*	*c*	*d*		*d*	*f*	*g*	*d*	*i*

[1] Numbers in this column are the number of meshes per "pouce" (=2.7 cm), and are the customary commercial designations of the sieves.

[2] Sieves designated by number of openings per cm^2 = square of number of meshes per cm.

[3] Also sieves with round holes; diameters, 1.5 mm, 3 mm, and 5 mm.

[4] Manufacturers commonly designate sieves by meshes per 26 mm.

[5] Material which passes a sieve of 9 or 10 meshes per cm is considered a "powder," and powders are graded, depending upon the country, in accordance with one of the following systems:

(*a*) Coarse, fine, very fine; (*b*) "farines," medium fine, fine, very fine; (*c*) coarse, medium, fine; (*d*) coarse, medium fine, fine, very fine; (*e*) coarse, medium fine, fine; (*f*) coarse, medium, fine, very fine; (*g*) coarse, medium coarse, medium fine, fine; (*h*) 20 to 30 mesh = coarse powder, 40 to 60 = powder, 80 to 120 = fine powder; (*i*) No. 12 = very coarse, No. 20 = coarse, No. 40 = moderately coarse, No. 50 = moderately fine; No. 60 = fine, No. 80 = very fine; No. 6, No. 30, and No. 100 also used.

[6] Silk sieves.

Table 4.—Bolting Cloth

Designation	Switzerland,* mesh per linear inch (=25.4 mm)		France
	Bodmer	Wydler	
No.			Designated by number of meshes per pouce (=27 mm)
0000	18	18	
000	23	23	
00	28	29	
0	38	38	
1	48	48	
2	54	54	
3	58	58	
4	62	62	
5	66	66	
6	74	74	
7	82	82	
8	86	86	
9	97	97	
10	109	109	
11	116	116	
12	124	125	
13	130	129	
14	139	140	
15	148	149	
16	157	157	
17	165	163	
18	170	166	
19	175	169	
20	180	175	
21	185	185	
25	200	197	

* The "quality" of the cloth is determined by the coarseness of the thread used. The figures given apply to the Standard, the Extra (X), and the Double Extra (XX) qualities. For the Triple Extra Heavy (XXX) quality the number of meshes per inch is in each case one less than the number given in the table. Diameter of threads is not specified. *Grit gauze* is designated by number of meshes per inch (= 25.4 mm) and is obtainable from No. 14 to No. 86.

Table 5.—Woven Sieves for Special Purposes (Metric Designation)

Sand and cement sieves, except as indicated for pharmaceutical sieves, *see* Table 3

In the body of the table are given the widths of the openings (O) in mm. If D = diameter of wire (mm) and N = number of meshes per cm, $D = 10/N - O$. Sieves are woven, except as noted. * indicates that neither D nor O is specified.

Meshes per cm²	64	144	225	324	900	2500	4900	5000	6400	
Meshes per cm = N =	8	12	15	18	30	50	70	70.71	80	
	Millimeters									
Austria	0.85	0.53			0.23		0.09			
Argentina					0.18		0.09			a
Belgium	0.85	0.53			0.18					
Brazil					*					
China	British sieves used to some extent. *See* Table 6									
Denmark					0.222	0.13		0.09		b, c
Finland					*		*			
France				0.36	0.18		0.09			d
Germany					0.222					b, e
Germany (for coal dust, etc.)[k]	Designation is N; $O = 6/N$; $D = 4/N$									
Great Britain	*See* Table 6									
Hungary	0.85	0.53			0.23		0.09			
Italy					0.18		0.09			
Japan	0.85	0.53	0.47		0.23					
Mexico	*See* Table 6									
Netherlands					0.23		0.09			f
Norway					0.23			0.09		
Portugal					*			*		g
Rumania					*		*			
Russia	0.85	0.53	0.47		0.23		0.09			h
Spain				0.36	0.18		0.09			
Sweden					0.222					b, i
Switzerland	0.85	0.53			0.23		0.09			j
United States of America	*See* Table 6									
Uruguay					*		*			

[a] Also copper plates with round holes 1.5 mm and 1.0 mm in diameter.

[b] Also, for cement sand, plate 0.25 mm thick with round holes 1.350 mm and 0.775 mm in diameter.

[c] For sand and pebbles, plates with round holes 60, 30, 15, 10, 5, 2, and 0.5 mm in diameter.

[d] Also plates with round holes 2, 1.5, 1, and 0.5 mm in diameter. For other woven sieves *see* Table 1.

[e] Commercial designations recognized: meshes per inch (25.4 mm), meshes per old French inch (= pouce = 27 mm), meshes per Rhenish in. (= Zoll = 26.15 mm) and meshes per cm, as well as meshes per cm².

[f] Sieves commonly designated by meshes per inch of 26 mm.

[g] French sieves are used in flour industry: British sieves, in mining industry.

[h] Sieves in common use are designated by meshes per linear inch, meshes per linear verchoc (44.45 mm), and meshes per cm².

[i] Tidbeck sieves are designated by meshes per inch of 25 mm.

[j] For other woven sieves, *see* Tables 1, 3, 4. For *Grit Gauze see* Table 4, footnote.

[k] Tolerance in mean value of $O = \pm 5\%$; max. deviation for N = 1 to 7 is ±10%, 8 to 20 is ±20%; 20 to 100 is ±30%. Tolerance in mean value of D for N = 1 to 4 is ±3%, 5 to 70 is ±4%, 80 to 100 is ±5%; max. deviation for same limits of N are ±6%, ±8%, ±10%, respectively. Series consists of N = 1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 14, 16, 20, 24, 30, 40, 50, 60, 70, 80, 100.

Table 6.—Woven Wire Sieves for Special Purposes* (Inch Designation)

American and British; for pharmaceutical sieves, *see* Table 3

D = diameter of wire; δD = amount by which the average D of all the wires in one direction may depart ($\pm$) from value specified for D: δn = allowable variation ($\pm$) in n per whole cm; max. [min.] = maximum [minimum] allowable value; N = approximate number of meshes per in.; n = number of meshes per cm; O = width of opening; S = specified value.

Sieve designation†	Unit of O, D, δD = 1 mm																Sieve designation‖	Unit of O, D = 1 mm		
	Cement and sand										Sand and fine highway material (cement concrete excepted). U. S. A.‡								Aggreg.‡¶ U. S.	Stone** G. B.
	U. S.‡§	Canada§	Mexico§	Great Britain††																
				O		n		D§												
N	O	O	O	S	Max.	Min.	Max.	S	Min.	Max.	O	n	δn	D	δD		O	D	D
10											2.00	3.9	0.04	0.56	0.05	3	76.0	6.3	
20	0.85	0.85		0.85	1.02	7.5	8.3	0.42	0.41	0.43	0.85	8	0.2	0.40	0.015	2	50.8	4.88	
30	0.57	0.57		0.57	0.69	11.4	12.2	0.27	0.27	0.28	0.50	12	0.4	0.33	0.012	$1\frac{1}{2}$	38.0	4.50	
40											0.36	16	0.6	0.26	0.010	1	25.4	4.12	3.7
50											0.29	20	0.8	0.21	0.010	$\frac{3}{4}$	19.0	3.42	3.7
76				0.224	0.28	29.1	30.7	0.112	0.107	0.117						$\frac{1}{2}$	12.7		3.0
80											0.17	31	1	0.15	0.008	$\frac{3}{8}$	9.5	2.33	2.6
100	0.14		0.14								0.14	39	1	0.116	0.008	$\frac{1}{4}$	6.4		2.3
180				0.097	0.127	69.3	72.4	0.046	0.041	0.051						$\frac{1}{8}$	3.2		1.8
200	0.074	0.074	0.066								0.074	79	3	0.053	0.005	$\frac{1}{16}$	1.6		1.4

* Sieves selected from the series given in Table 1 are not separately considered here.

† Designation is meshes per inch, or meshes per inch² in the form "10 × 10," etc.

‡ Sieves specified by American Society for Testing Materials; also wire sieves of 400 meshes per cm² are specified for certain chemical analyses of metals; for coke, sieves with openings, 2.5, 1.75, 1.25, 0.75, and 0.5 in. wide are used. *See also* Table 1.

§ $D + O = 25.4/N$.

‖ Designation is width of opening in inches; British use the form 3 × 3, etc.

¶ Concrete aggregates. Tolerance: average opening, ±3 %; max. O, ±10 %; D, ±10 %.

** Stone chippings. For broken stone, *see* Table 7.

†† British Engineering Standards Committee's sieves. Frames 203.20 mm square, at least 69.85 cm deep; cloth woven (not twilled).

Table 7.—Gages for Broken Stone and Slag, Etc.

American and British

U. S. A.*						Great Britain†	
Diameter		Diameter		Diameter		Size of stone	Diameter of hole
in.	mm	in.	mm	in.	mm		mm
4	101.6	2	50.8	0.75	19.0	3-in.	76.2
3.5	88.9	1.5	38.1	0.5	12.7	2.5-in.	63.5
3	76.2	1.25	31.8	0.25	6.4	2-in.	50.8
2.5	63.5	1	25.4			1.5-in.	38.1

* Round holes, specified by their diameters in inches. For sizing gypsum rings 76, 38, and 25 mm in diameter are used.

† Gages are of sheet metal at least 5 mm thick and contain both circular holes and slots.

SACCHARIMETRY, THE PROPERTIES OF COMMERCIAL SUGARS AND THEIR SOLUTIONS

Frederick Bates, F. P. Phelps, C. F. Snyder

Properties.—Under each sugar the various properties of the sugar and its solutions are given in the following order: optical rotation, refractive index, density, solubility, mutarotation, hydrolysis and decomposition.

Propriétés.—Sous chaque sucre on trouvera les propriétés variées du sucre et de ses solutions disposées dans l'ordre suivant: rotation optique, indice de réfraction, densité, solubilité, mutarotation, hydrolyse et décomposition.

Eigenschaften.—Unter jedem Zucker werden die verschiedenen Eigenschaften und die seiner Lösungen in folgender Ordung angegeben: Rotation, Refraktions-Index, Dichte, Löslichkeit, Multirotation, Hydrolyse und Zersetzung.

Proprietà.—Per ogni zucchero, le sue proprietà e quelle delle soluzioni sono riportate nell'ordine seguente: rotazione ottica, indice di rifrazione, densità, solubilità, mutarotazione idrolisi e scomposizione.

INTRODUCTION

Saccharimetric Methods and Standards

Specific Rotation.—The specific rotation $[\alpha]$ of any substance in the dissolved state is represented and defined by the equation

$$[\alpha]^{t^\circ}_X = \frac{\alpha}{lC} = \frac{\alpha}{lpd}$$

where t designates the temperature of measurement, X is a character used to identify the wave length of the light source used, α is the observed rotation in circ. deg., l the length of the solution in dm, C its concentration in g per ml at $t°$, p its concentration in wt. %, and d its density in g/ml at $t°$. $[\alpha]$ varies with X, and to a less extent with t and C (or p). Wherever possible the values of the specific rotations of the more important sugars are given at definite intervals of concentration. $[\alpha]$ for all intermediate concentrations may be found by interpolation.

Saccharimetric Method.—Since monochromatic light sources are difficult to obtain, it is frequently more convenient to use a white-light source and a quartz-wedge saccharimeter. This saccharimeter is particularly applicable to the sugar group because the rotatory dispersions of quartz and the common sugars are very similar. The conditions for accurate observing are improved if the violet end of the spectrum is absorbed by the potassium bichromate cell. The saccharimetric scale is defined by the rotation of sucrose, its hundred point being the rotation of 26 g (in air, d = 0.0012, brass weights) in 100 ml of solution. Therefore in order to determine a sugar having a different rotatory power, the weight used must be adjusted to the sucrose scale, *i.e.*, the sac-

charimetric normal weight of the sugar in question is that weight which, dissolved in 100 ml of solution, will give a rotation of 100° on the sucrose scale. To compute this weight use, whenever the data are available, the results of direct determinations of the values of the rotations on the sucrose scale.

In the case of the first four sugars of the following table, determinations have been made of the relation between the rotation in sucrose deg. (°S) and circ. deg. of sodium light for the same solution. If this relation is known, the saccharimetric normal weight for the saccharimeter can be computed from the known specific rotation.

In the case of many sugars no direct determinations of the relative values of the sugar deg. and circ. deg. are available, and in these instances the saccharimetric normal weight must be computed from the relative specific rotations of sucrose and of the sugar in question on the assumption that the rotation dispersion of all the sugars is the same as that of sucrose, which is not strictly true. Saccharimetric normal weights so computed must therefore be considered only as the nearest approximation at present available. The computation depends upon the assumption that the saccharimetric normal weights of the sugars vary inversely as their specific rotations.

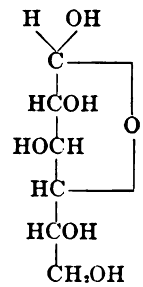
Saccharimetric Normal Weights, W_N

In air, d = 0.0012, brass weights

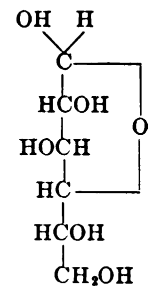
Sugar	1°S =	W_N
Dextrose	0.3448	32.248
Lactose	.3452	32.857
Maltose	.3449	12.474
Raffinose ($5H_2O$)	.3450	16.507
Levulose	calc.	18.592
Invert sugar	calc.	86.450

Thus in the determination of these sugars it is merely necessary to weigh out the appropriate normal weight of the sugar and proceed exactly as in the analysis of sucrose. The specific rotation is in general not exactly proportional to the concentration of the sugar, and for accurate work a correction should be applied for readings which vary much from the 100° point. Many experimenters advise using a variable saccharimetric normal weight according to the concentration of the sugar taken, but this requires a previous knowledge of the quantity of sugar present or a preliminary assay of the material. It is more convenient to use a uniform saccharimetric normal weight and to apply a correction for the various parts of the sugar scale.

Mutarotation.—In a very large class of sugars a considerable lapse of time is required for the dissolved sugar to exhibit a stable rotatory power. The rotation of the freshly prepared solution in general steadily changes according to the laws of unimolecular reactions, to a steady state, where no further change occurs. This phenomenon is called "mutarotation." The specific rotation of the sugar is commonly expressed in terms of this equilibrium condition. Mutarotation has been satisfactorily explained by the discovery of two modifications of each of the sugars in which the phenomenon exists. These two modifications have been designated the α- and β-forms. When the sugar crystallizes, but one of these forms separates from solution, usually on account of a considerable difference in solubility, and, consequently, when a fresh solution is prepared the rotatory power of this form is exhibited. The most plausible explanation of the isomerism of the α- and β-forms is connected with the end carbon atom which is capable of changing its relation to the rest of the molecule. For example, in the case of dextrose the mutarotation reaction is regarded as a balanced reaction between the two forms:—



α-d-Glucose
$[\alpha]_D^{20}$ = 113.4°



β-d-Glucose
$[\alpha]_D^{20}$ = +19.0°

The steady state is, under this hypothesis, a state in which the reaction velocities $\alpha \rightarrow \beta$ and $\beta \rightarrow \alpha$ are equal.

As the change of one form into the other obeys the laws of mass action and appears to be a unimolecular reaction, the mutarotation constant is expressed by the formula

$$k_1 + k_2 = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty},$$

r_0 and r_∞ being the initial and final rotations, and r_t the rotation at the time, t, from the start.

International Sugar Scale.—The Ventzke sugar scale, although in general use for many years, has never been fully understood by polariscopists generally. This has led to much confusion and to the use of 100 ml flasks on instruments standardized for use with the Mohr flask. In addition, 17.5°C is well below the temperature of the average laboratory. Because of these and other considerations the International Sugar Commission at the Paris meeting in 1900 recommended the use of a new definition of the 100° point based upon true ml and a standard temperature of 20°C. In order to divorce it as completely as possible from confusion with the Ventzke scale, the new scale is referred to as the international sugar scale because of its origin. The change to 20°C necessitated a change in the saccharimetric normal weight in order to keep the new scale comparable with the Ventzke. Correcting for the change in the specific rotation (−0.000184), the expansion of a glass tube (+0.000008), quartz wedge (−0.000130), and metal scale (−0.000018), the new weight becomes 26.000+ g. The *international sugar scale* was then defined at the Paris meeting as follows: The graduation of the saccharimeter and all readings shall be made at 20°C; 26 g (in air, d = 0.0012, brass weights) of sucrose are dissolved in water and the volume made up to 100 ml at 20°C. This will determine the 100° point.

Standardization of International Sugar Scale.—The 100°S point on the international sugar scale was determined by Herzfeld and Schönrock in 1900–1904 (33, 82), with the result that 100°S = 34.657° (λ = 589.25mμ). In 1916 Bates and Jackson (9) of the Bureau of Standards, as the result of an elaborate investigation, found that 100°S = 34.620 (λ = 589.25mμ). They found that the saccharimetric normal sucrose solution as defined by the International Sugar Commission did not read 100°S on saccharimeters standardized on the Herzfeld-Schönrock basis. Subsequently additional investigations were carried out at the Institut für Zucker-Industrie (52) and at the Research Institute for the Czechoslovakian Sugar Industry (87). The readings of the saccharimetric normal sucrose solution on the original Herzfeld-Schönrock scale are given in the following table:

Original Herzfeld-Schönrock determination	1900–1904	100.00°S (33, 82)
Bates and Jackson	1916	99.895 (99.870–99.91) (9)
Stanek	1921	(99.81–99.90) (87)
Kraisy and Traegel	1924	99.834 (99.775–99.895) (52)

Saccharimetric Scale Conversion Factors.—Comparisons may be made between the readings of different scales by means of the following conversion factors: 1° International sugar scale = 0.34620° angular rotation D; 1° French sugar scale = 0.21666° angular rotation D; 1° Wild sugar scale = 0.13284° angular rotation D. (Saccharimetric normal weight = 26.00 g International scale = 16.29 g French scale = 10.00 g Wild scale.)

Quartz Control Plates.—The accuracy of the readings on the quartz wedge saccharimeter is checked by means of quartz control plates accurately standardized for the mercury line, $\lambda = 546.1 m\mu$. In order to obtain a quartz rotation for $\lambda = 589.25$, use the equation

$$\frac{\phi_{\lambda-589.25}}{\phi_{\lambda-546.1}} = 0.85085 \quad (6, 9)$$

where ϕ is the rotation in circ. deg. By this method the errors due to the character of the sodium source of light are eliminated and the measurements of one observer may be readily compared with those of another. The rotation of quartz in circ. deg. at a temperature t is given by:

$$\phi_t = \phi_0 (1 + 0.000144t), \text{ between 4 and 50°C}$$

THICKNESS OF THE NORMAL QUARTZ PLATE (9)

Wave length of light source, Å	Rotation of normal plate (Bates and Jackson)	Rotation of 1 mm of quartz at 20°C; light parallel to optic axis	Thickness of normal plate, mm
5892.5	34.620°	21.7182° (Gumlich)	1.5940
5892.5	34.620°	21.7283° (Lowry)	1.5934
5461	40.690°	25.5371° (Lowry)	1.5934

Rotation of Normal Quartz Plate (9). Normal quartz plate = 100°S = 34.620° (λ = 5892.5 Å) at 20°C; 1° (λ = 5892.5 Å) = 2.8885°S. Normal quartz plate = 100°S = 40.690° (λ = 5461 Å) at 20°C; 1° (λ = 5461 Å) = 2.4576°S.

Absolute Rotation of Saccharimetric Normal Sucrose Solutions (9).—The rotation of the saccharimetric normal sucrose solution for λ = 5461 Å by direct measurement is: 100° sucrose = 40.763° of arc. Since the rotation ratio for the saccharimetric normal solution for λ = 5892.5 Å and λ = 5461 Å is 0.84922° the rotation of the saccharimetric normal solution for λ = 5892.5 Å is 34.617°.

Rotation Ratios for Quartz and for Sucrose Solutions (9).—The ratios of the rotations in circ. deg. of quartz and of sucrose solutions for two wave lengths are as follows: For quartz $\frac{\phi^{20}_{\lambda-5892.5\text{Å}}}{\phi^{20}_{\lambda-5461\text{Å}}}$ = 0.85085 and for sucrose $\frac{\phi^{20}_{-5892.5\text{Å}}}{\phi^{20}_{-5461\text{Å}}}$ = 0.84922.

Rotatory Dispersion Curves of Quartz and of Sucrose Solution (9).—The difference between the rotations of the normal quartz plate and the saccharimetric normal sucrose solution for $\lambda = 589.25 m\mu$ is 0.003° and for $\lambda = 546.1 m\mu$, 0.073°. The values indicate that the rotatory dispersion curves of plate and solution cross at about $\lambda = 585 m\mu$. The reading of the saccharimetric normal solution on the true saccharimeter scale with the source $\lambda = 589.25 m\mu$ has been calculated to be 99.99°S.

Rotation Difference, in Sucrose Degrees, for Saccharimetric Normal Sucrose Solution between λ = 5461 Å and λ = 5892.5 Å.—Saccharimeter reading (λ = 5461 Å) − saccharimeter reading (λ = 5892.5 Å) = 0.19₂°S (9).

$C_{12}H_{22}O_{11}$, SUCROSE

(Composition: Levulose < > Dextrose)

Optical Rotation

IN H_2O

(p = wt. % sucrose; C = g sucrose per 100 ml solution). $[\alpha]_D^{20} = 66.386° + 0.01503_5p - 0.000398_6p^2$ [Tollens (88)]. $[\alpha]_D^{20} = 66.438° + 0.01031_2p - 0.000354_5p^2$ [Nasini and Villavecchia (67)]. Landolt (55) has combined the above giving: $[\alpha]_D^{20} = 66.435° + 0.00870C - 0.00023C^2$, ($C$ from 0 to 65) or, $[\alpha]_D^{20} = 66.412° + 0.01267_3p - 0.000376_5p^2$ between p = 0 and 50 wt. %; all weights *in vacuo*.

λ, (mμ)	589.25 (D)		546.1		Based on weights *in vacuo*
$[\alpha]_\lambda^{20}$	66.53	66.50	78.34	78.29	
Lit.	(9)	(84)	(9)	(84)	

SPECIFIC ROTATION OF SUCROSE IN H_2O FOR DIFFERENT WAVE LENGTHS

λ, mμ	$[\alpha]^{18}$ (70)
589	66.8
500	99.8
450	122.2
400	149.9
350	192.9
300	297.7
250	543.0
λ, mμ	**$[\alpha]^{22}$ (46)**
1300	11.93
1200	14.21
1100	17.02
1000	20.76
900	26.32
800	33.93
700	44.68
600	62.48
λ, mμ	**$[\alpha]^{20}$ (59)**
Li, 670.8	50.51
Cd, 643.8	55.04
Zn, 636.2	56.51
Na, 589.3	66.45
Cu, 578.2	69.10
Hg, 578.0	69.22
Cu, 570.0	71.24

λ, mμ	$[\alpha]^{20}$ (59)
Hg, 546.1	78.16
Cu, 521.8	86.21
Cu, 515.3	88.68
Cu, 510.6	90.46
Cd, 508.6	91.16
Zn, 481.1	103.07
Cd, 480.0	103.62
Zn, 472.2	107.38
Zn, 468.0	109.49
Cd, 467.8	109.69
Fe, 438.4	126.5
Fe, 437.6	127.2
Hg, 435.8	128.49
Fe, 435.3	128.5
Fe, 433.7	129.8
Fe, 431.5	130.7
Fe, 428.2	133.6
Fe, 427.2	134.2
Fe, 426.1	134.9
Fe, 419.1	140.0
Fe, 414.4	144.2
Fe, 388.9	166.7
Fe, 383.3	171.8
Fe, 382.6	173.1

VALUES OF $[\alpha]_\lambda^{20}$ FOR SUCROSE IN WATER AND IN PYRIDINE (30)

C = moles sucrose per liter of solution

C / λ, (mμ)	Water			Pyridine		
	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
656	53.18	53.32	53.48	64.86	65.44	65.98
589	66.5	66.71	66.81	84.37	85.10	85.89
535	82.25	82.76	82.93	99.22	100.87	101.86
508	91.53	91.79	92.59	114.37	116.15	118.01
479	104.24	104.67	105.42	133.67	135.5	137.23
447	121.63	122.80	123.80	152.25	154.38	156.57

SUCROSE IN PYRIDINE (96)

% S	0	1	2	4	6.25
d_4^{25}	0.9735	0.9805	0.9829	0.9912	1.0010
$[\alpha]_D^{25}$		86.7	85.9	84.7	83.6

t, °C	−10	0	+10	25	45	65	85	105
d_4^t	1.034	1.0248	1.0510	1.00005	0.9811	0.9619	0.9420	0.9220
$[\alpha]_D^t$	88.7	87.3	85.6	83.8	82.0	80.3	78.5	77.0

EFFECT OF SALTS ON THE ROTATION OF SUCROSE IN H_2O AT 20°C

The rotation in deg. S of a saccharimetric normal sucrose solution containing m grams of salt per 100 ml of solution is expressed by the equation $R = 100 - am$, where a has the following values:

Salt	NaCl	NH_4Cl	$K_2C_2O_4$	$CaCl_2$	$Pb(C_2H_3O_2)_2$; v. Fig. 1			
a	0.265	0.169	0.234	0.339	m	1.0	2.0	5.0
m_{max}	3.7	6.8	4.0	3.3	$R - 100$	0.03	0.04	0.11

$[\alpha]_D^{25}$ for a 9.60% sucrose solution containing NaCl is expressed by the equation $[\alpha]_D^{25} = 66.410 - 1.456r$ for values of r up to 1.3; r = ratio, g NaCl to g sugar [91, 92, 93].

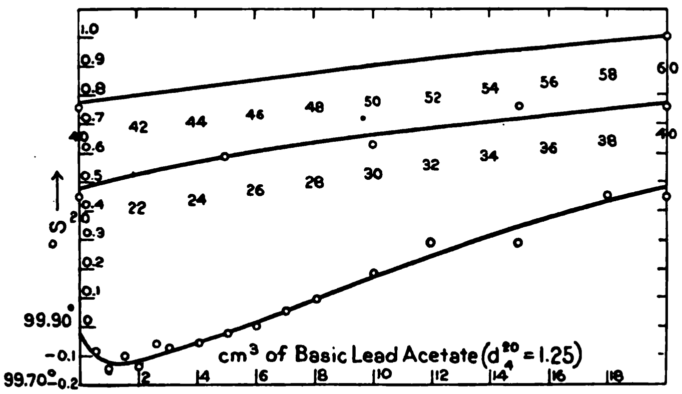


Fig. 1.

Refractive Index

Refractive Index of Aqueous Sucrose Solutions at 20°C [83]

Schönrock's table for determining water in sucrose solutions by means of the Abbe refractometer [83]

n_D^{20}	$\%H_2O$	n_D^{20}	$\%H_2O$	n_D^{20}	$\%H_2O$
1.3330	100.0	1.3374	97.0	1.3418	94.0
1.3331	99.9	1.3375	96.9	1.3419	93.9
1.3333	99.8	1.3377	96.8	1.3421	93.8
1.3334	99.7	1.3378	96.7	1.3423	93.7
1.3336	99.6	1.3380	96.6	1.3424	93.6
1.3337	99.5	1.3381	96.5	1.3425	93.5
1.3338	99.4	1.3382	96.4	1.3427	93.4
1.3340	99.3	1.3384	96.3	1.3429	93.3
1.3341	99.2	1.3385	96.2	1.3430	93.2
1.3342	99.1	1.3387	96.1	1.3431	93.1
1.3344	99.0	1.3388	96.0	1.3433	93.0
1.3345	98.9	1.3389	95.9	1.3435	92.9
1.3347	98.8	1.3391	95.8	1.3436	92.8
1.3348	98.7	1.3393	95.7	1.3437	92.7
1.3350	98.6	1.3394	95.6	1.3439	92.6
1.3351	98.5	1.3395	95.5	1.3441	92.5
1.3353	98.4	1.3397	95.4	1.3442	92.4
1.3355	98.3	1.3399	95.3	1.3443	92.3
1.3356	98.2	1.3400	95.2	1.3445	92.2
1.3357	98.1	1.3401	95.1	1.3447	92.1
1.3359	98.0	1.3403	95.0	1.3448	92.0
1.3361	97.9	1.3405	94.9	1.3450	91.9
1.3362	97.8	1.3406	94.8	1.3451	91.8
1.3363	97.7	1.3407	94.7	1.3453	91.7
1.3365	97 6	1.3409	94.6	1.3454	91.6
1.3367	97.5	1.3411	94.5	1.3456	91.5
1.3368	97.4	1.3412	94.4	1.3458	91.4
1.3369	97.3	1.3413	94.3	1.3459	91.3
1.3371	97.2	1.3415	94.2	1.3461	91.2
1.3373	97.1	1.3417	94.1	1.3462	91.1

n_D^{20}	$\%H_2O$	n_D^{20}	$\%H_2O$	n_D^{20}	$\%H_2O$
1.3464	91.0	1.3549	85.5	1.3639	80.0
1.3465	90.9	1.3551	85.4	1.3641	79.9
1.3467	90.8	1.3552	85.3	1.3642	79.8
1.3469	90.7	1.3554	85.2	1.3644	79.7
1.3470	90.6	1.3555	85.1	1.3645	79.6
1.3471	90.5	1.3557	85.0	1.3647	79.5
1.3473	90.4	1.3559	84.9	1.3649	79.4
1.3475	90.3	1.3560	84.8	1.3650	79.3
1.3476	90.2	1.3562	84.7	1.3652	79.2
1.3477	90.1	1.3563	84.6	1.3653	79.1
1.3479	90.0	1.3565	84.5	1.3655	79.0
1.3481	89.9	1.3567	84.4	1.3657	78.9
1.3482	89.8	1.3568	84.3	1.3658	78.8
1.3483	89.7	1.3570	84.2	1.3660	78.7
1.3485	89.6	1.3571	84.1	1.3662	78.6
1.3487	89.5	1.3573	84.0	1.3663	78.5
1.3488	89.4	1.3575	83.9	1.3665	78.4
1.3489	89.3	1.3576	83.8	1.3667	78.3
1.3491	89.2	1.3578	83.7	1.3669	78.2
1.3493	89.1	1.3580	83.6	1.3670	78.1
1.3494	89.0	1.3582	83.5	1.3672	78.0
1.3496	88.9	1.3583	83.4	1.3674	77.9
1.3497	88.8	1.3585	83.3	1.3675	77.8
1.3499	88.7	1.3587	83.2	1.3677	77.7
1.3500	88.6	1.3588	83.1	1.3679	77.6
1.3502	88.5	1.3590	83.0	1.3681	77.5
1.3504	88.4	1.3592	82.9	1.3682	77.4
1.3505	88.3	1.3593	82.8	1.3684	77.3
1.3507	88.2	1.3595	82.7	1.3686	77.2
1.3508	88.1	1.3596	82.6	1.3687	77.1
1.3510	88.0	1.3598	82.5	1.3689	77.0
1.3512	87.9	1.3600	82.4	1.3691	76.9
1.3513	87.8	1.3601	82.3	1.3692	76.8
1.3515	87.7	1.3603	82.2	1.3694	76.7
1.3516	87.6	1.3604	82.1	1.3696	76.6
1.3518	87.5	1.3606	82.0	1.3698	76.5
1.3520	87.4	1.3608	81.9	1.3699	76.4
1.3521	87.3	1.3609	81.8	1.3701	76.3
1.3523	87.2	1.3611	81.7	1.3703	76.2
1.3524	87.1	1.3612	81.6	1.3704	76.1
1.3526	87.0	1.3614	81.5	1.3706	76.0
1.3527	86.9	1.3616	81.4	1.3708	75.9
1.3529	86.8	1.3617	81.3	1.3709	75.8
1.3531	86.7	1.3619	81.2	1.3711	75.7
1.3532	86.6	1.3620	81.1	1.3713	75.6
1.3533	86.5	1.3622	81.0	1.3715	75.5
1.3535	86.4	1.3624	80.9	1.3716	75.4
1.3537	86.3	1.3625	80.8	1.3718	75.3
1.3538	86.2	1.3627	80.7	1.3720	75.2
1.3539	86.1	1.3629	80.6	1.3721	75.1
1.3541	86.0	1.3631	80.5	1.3723	75.0
1.3543	85.9	1.3632	80.4	1.3725	74.9
1.3544	85.8	1.3634	80.3	1.3726	74.8
1.3546	85.7	1.3636	80.2	1.3728	74.7
1.3547	85.6	1.3637	80.1	1.3730	74.6

n_D^{20}	% H_2O	n_D^{20}	% H_2O	n_D^{20}	% H_2O	n_D^{20}	% H_2O	n_D^{20}	% H_2O	n_D^{20}	% H_2O
1.3731	74.5	1.3829	69.0	1.3929	63.5	1.4036	58.0	1.4147	52.5	1.4264	47.0
1.3733	74.4	1.3831	68.9	1.3931	63.4	1.4038	57.9	1.4150	52.4	1.4266	46.9
1.3735	74.3	1.3833	68.8	1.3933	63.3	1.4040	57.8	1.4152	52.3	1.4268	46.8
1.3737	74.2	1.3834	68.7	1.3935	63.2	1.4042	57.7	1.4154	52.2	1.4270	46.7
1.3738	74.1	1.3836	68.6	1.3937	63.1	1.4044	57.6	1.4156	52.1	1.4272	46.6
1.3740	74.0	1.3838	68.5	1.3939	63.0	1.4046	57.5	1.4158	52.0	1.4275	46.5
1.3742	73.9	1.3840	68.4	1.3941	62.9	1.4048	57.4	1.4160	51.9	1.4277	46.4
1.3744	73.8	1.3842	68.3	1.3943	62.8	1.4050	57.3	1.4162	51.8	1.4279	46.3
1.3745	73.7	1.3843	68.2	1.3945	62.7	1.4052	57.2	1.4164	51.7	1.4281	46.2
1.3747	73.6	1.3845	68.1	1.3947	62.6	1.4054	57.1	1.4166	51.6	1.4283	46.1
1.3749	73.5	1.3847	68.0	1.3949	62.5	1.4056	57.0	1.4169	51.5	1.4285	46.0
1.3751	73.4	1.3849	67.9	1.3950	62.4	1.4058	56.9	1.4171	51.4	1.4287	45.9
1.3753	73.3	1.3851	67.8	1.3952	62.3	1.4060	56.8	1.4173	51.3	1.4289	45.8
1.3754	73.2	1.3852	67.7	1.3954	62.2	1.4062	56.7	1.4175	51.2	1.4292	45.7
1.3756	73.1	1.3854	67.6	1.3956	62.1	1.4064	56.6	1.4177	51.1	1.4294	45.6
1.3758	73.0	1.3856	67.5	1.3958	62.0	1.4066	56.5	1.4179	51.0	1.4296	45.5
1.3760	72.9	1.3858	67.4	1.3960	61.9	1.4068	56.4	1.4181	50.9	1.4298	45.4
1.3761	72.8	1.3860	67.3	1.3962	61.8	1.4070	56.3	1.4183	50.8	1.4300	45.3
1.3763	72.7	1.3861	67.2	1.3964	61.7	1.4072	56.2	1.4185	50.7	1.4303	45.2
1.3765	72.6	1.3863	67.1	1.3966	61.6	1.4074	56.1	1.4187	50.6	1.4305	45.1
1.3767	72.5	1.3865	67.0	1.3968	61.5	1.4076	56.0	1.4189	50.5	1.4307	45.0
1.3768	72.4	1.3867	66.9	1.3970	61.4	1.4078	55.9	1.4192	50.4	1.4309	44.9
1.3770	72.3	1.3869	66.8	1.3972	61.3	1.4080	55.8	1.4194	50.3	1.4311	44 8
1.3772	72.2	1.3870	66.7	1.3974	61.2	1.4082	55.7	1.4196	50.2	1.4313	44.7
1.3773	72.1	1.3872	66.6	1.3976	61.1	1.4084	55.6	1.4198	50.1	1.4316	44.6
1.3775	72.0	1.3874	66.5	1.3978	61.0	1.4086	55.5	1.4200	50.0	1.4318	44.5
1.3777	71.9	1.3876	66.4	1.3980	60.9	1.4088	55.4	1.4202	49.9	1.4320	44.4
1.3779	71.8	1.3878	66.3	1.3982	60.8	1.4090	55.3	1.4204	49.8	1.4322	44.3
1.3780	71.7	1.3879	66.2	1.3984	60.7	1.4092	55.2	1.4206	49.7	1.4325	44.2
1.3782	71.6	1.3881	66.1	1.3986	60.6	1.4094	55.1	1.4208	49.6	1.4327	44.1
1.3784	71.5	1.3883	66.0	1.3987	60.5	1.4096	55.0	1.4211	49.5	1.4329	44.0
1.3786	71.4	1.3885	65.9	1.3989	60.4	1.4098	54.9	1.4213	49.4	1.4331	43.9
1.3788	71.3	1.3887	65.8	1.3991	60.3	1.4100	54.8	1.4215	49.3	1.4333	43.8
1.3789	71.2	1.3889	65.7	1.3993	60.2	1.4102	54.7	1.4217	49.2	1.4336	43.7
1.3791	71.1	1.3891	65.6	1.3995	60.1	1.4104	54.6	1.4219	49.1	1.4338	43.6
1.3793	71.0	1.3893	65.5	1.3997	60.0	1.4107	54.5	1.4221	49.0	1.4340	43.5
1.3795	70.9	1.3894	65.4	1.3999	59.9	1.4109	54.4	1.4223	48.9	1.4342	43.4
1.3797	70.8	1.3896	65.3	1.4001	59.8	1.4111	54.3	1.4225	48.8	1.4344	43.3
1.3798	70.7	1.3898	65.2	1.4003	59.7	1.4113	54.2	1.4227	48.7	1.4347	43.2
1.3800	70.6	1.3900	65.1	1.4005	59.6	1.4115	54.1	1.4229	48.6	1.4349	43.1
1.3802	70.5	1.3902	65.0	1.4007	59.5	1.4117	54.0	1.4231	48.5	1.4351	43.0
1.3804	70.4	1.3904	64.9	1.4008	59.4	1.4119	53.9	1.4234	48.4	1.4353	42.9
1.3806	70.3	1.3906	64.8	1.4010	59.3	1.4121	53.8	1.4236	48.3	1.4355	42.8
1.3807	70.2	1.3907	64.7	1.4012	59.2	1.4123	53.7	1.4238	48.2	1.4358	42.7
1.3809	70.1	1.3909	64.6	1.4014	59.1	1.4125	53.6	1.4240	48.1	1.4360	42.6
1.3811	70.0	1.3911	64.5	1.4016	59.0	1.4127	53.5	1.4242	48.0	1.4362	42.5
1.3813	69.9	1.3913	64.4	1.4018	58.9	1.4129	53.4	1.4244	47.9	1.4364	42.4
1.3815	69.8	1.3915	64.3	1.4020	58.8	1.4131	53.3	1.4246	47.8	1.4366	42.3
1.3816	69.7	1.3916	64.2	1.4022	58.7	1.4133	53.2	1.4249	47.7	1.4369	42.2
1.3818	69.6	1.3918	64.1	1.4024	58.6	1.4135	53.1	1.4251	47.6	1.4371	42.1
1.3820	69.5	1.3920	64.0	1.4026	58.5	1.4137	53.0	1.4253	47.5	1.4373	42.0
1.3822	69.4	1.3922	63.9	1.4028	58.4	1.4139	52.9	1.4255	47.4	1.4375	41.9
1.3824	69.3	1.3924	63.8	1.4030	58.3	1.4141	52.8	1.4257	47.3	1.4378	41.8
1.3825	69.2	1.3926	63.7	1.4032	58.2	1.4143	52.7	1.4260	47.2	1.4380	41.7
1.3827	69.1	1.3928	63.6	1.4034	58.1	1.4145	52.6	1.4262	47.1	1.4382	41.6

n_D^{20}	%H_2O
1.4385	41.5
1.4387	41.4
1.4389	41.3
1.4391	41.2
1.4394	41.1
1.4396	41.0
1.4398	40.9
1.4400	40.8
1.4403	40.7
1.4405	40.6
1.4407	40.5
1.4409	40.4
1.4411	40.3
1.4414	40.2
1.4416	40.1
1.4418	40.0
1.4420	39.9
1.4423	39.8
1.4425	39.7
1.4427	39.6
1.4429	39.5
1.4432	39.4
1.4434	39.3
1.4436	39.2
1.4439	39.1
1.4441	39.0
1.4443	38.9
1.4446	38.8
1.4448	38.7
1.4450	38.6
1.4453	38.5
1.4455	38.4
1.4457	38.3
1.4459	38.2
1.4462	38.1
1.4464	38.0
1.4466	37.9
1.4468	37.8
1.4471	37.7
1.4473	37.6
1.4475	37.5
1.4477	37.4
1.4479	37.3
1.4482	37.2
1.4484	37.1
1.4486	37.0
1.4488	36.9
1.4491	36.8
1.4493	36.7
1.4495	36.6
1.4497	36.5
1.4500	36.4
1.4502	36.3
1.4504	36.2
1.4507	36.1
1.4509	36.0
1.4511	35.9
1.4514	35.8
1.4516	35.7
1.4518	35.6
1.4521	35.5
1.4523	35.4
1.4525	35.3
1.4527	35.2
1.4530	35.1
1.4532	35.0
1.4534	34.9
1.4537	34.8
1.4539	34.7
1.4541	34.6
1.4544	34.5
1.4546	34.4
1.4548	34.3
1.4550	34.2
1.4553	34.1
1.4555	34.0*
1.4558	34.0
1.4561	33.9
1.4563	33.8
1.4565	33.7
1.4567	33.6
1.4570	33.5
1.4572	33.4
1.4574	33.3
1.4577	33.2
1.4579	33.1
1.4581	33.0
1.4584	32.9
1.4586	32.8
1.4588	32.7
1.4591	32.6
1.4593	32.5
1.4595	32.4
1.4598	32.3
1.4600	32.2
1.4602	32.1
1.4605	32.0
1.4607	31.9
1.4609	31.8
1.4612	31.7
1.4614	31.6
1.4616	31.5
1.4619	31.4
1.4621	31.3
1.4623	31.2
1.4625	31.1
1.4628	31.0
1.4630	30.9
1.4632	30.8
1.4635	30.7
1.4637	30.6
1.4639	30.5
1.4642	30.4
1.4644	30.3
1.4646	30.2
1.4649	30.1
1.4651	30.0
1.4653	29.9
1.4656	29.8
1.4658	29.7
1.4661	29.6
1.4663	29.5
1.4666	29.4
1.4668	29.3
1.4671	29.2
1.4673	29.1
1.4676	29.0
1.4678	28.9
1.4681	28.8
1.4683	28.7
1.4685	28.6
1.4688	28.5
1.4690	28.4
1.4693	28.3
1.4695	28.2
1.4698	28.1
1.4700	28.0
1.4703	27.9
1.4705	27.8
1.4708	27.7
1.4710	27.6
1.4713	27.5
1.4715	27.4
1.4717	27.3
1.4720	27.2
1.4722	27.1
1.4725	27.0
1.4727	26.9
1.4730	26.8
1.4732	26.7
1.4735	26.6
1.4737	26.5
1.4740	26 4
1.4742	26.3
1.4744	26.2
1.4747	26.1
1.4749	26.0
1.4752	25.9
1.4754	25.8
1.4757	25.7
1.4759	25.6
1.4762	25.5
1.4764	25.4
1.4767	25.3
1.4769	25.2
1.4772	25.1
1.4774	25.0
1.4777	24.9
1.4779	24.8
1.4782	24.7
1.4784	24.6
1.4787	24.5
1.4789	24.4
1.4792	24.3
1.4794	24.2
1.4797	24.1
1.4799	24.0
1.4802	23.9
1.4804	23.8
1.4807	23.7
1.4810	23.6
1.4812	23.5
1.4815	23.4
1.4817	23.3
1.4820	23.2
1.4822	23.1
1.4825	23.0
1.4827	22.9
1.4830	22.8
1.4832	22.7
1.4835	22.6
1.4838	22.5
1.4840	22.4
1.4843	22.3
1.4845	22.2
1.4848	22.1
1.4850	22.0
1.4853	21.9
1.4855	21.8
1.4858	21.7
1.4860	21.6
1.4863	21.5
1.4865	21.4
1.4868	21.3
1.4871	21.2
1.4873	21.1
1.4876	21.0
1.4878	20.9
1.4881	20.8
1.4883	20.7
1.4886	20.6
1.4888	20.5
1.4891	20.4
1.4893	20.3
1.4896	20.2
1.4898	20.1
1.4901	20.0
1.4904	19.9
1.4906	19.8
1.4909	19.7
1.4912	19.6
1.4914	19.5
1.4917	19.4
1.4919	19.3
1.4922	19.2
1.4925	19.1
1.4927	19.0
1.4930	18.9
1.4933	18.8
1.4935	18.7
1.4938	18.6
1.4941	18.5
1.4943	18.4
1.4946	18.3
1.4949	18.2
1.4951	18.1
1.4954	18.0
1.4956	17.9
1.4959	17.8
1.4962	17.7
1.4964	17.6
1.4967	17.5
1.4970	17.4
1.4972	17.3
1.4975	17.2
1.4978	17.1
1.4980	17.0
1.4983	16.9
1.4985	16.8
1.4988	16.7
1.4991	16.6
1.4993	16.5
1.4996	16.4
1.4999	16.3
1.5001	16.2
1.5004	16.1
1.5007	16.0
1.5009	15.9
1.5012	15.8
1.5015	15.7
1.5017	15.6
1.5020	15.5
1.5022	15.4
1.5025	15.3
1.5028	15.2
1.5030	15.1
1.5033	15.0

* The values of the refractive index from 34 to 15% are taken from Main's table (61.5).

Refractive Index Correction Table for Readings at Temperatures Other than 20°C (86)

°C \ %H_2O	95	90	85	80	70	60	50	40	30	25
	To be added to % water									
15	0.25	0.27	0.31	0.31	0.34	0.35	0.36	0.37	0.36	0.36
16	0.21	0.23	0.26	0.27	0.29	0.31	0.31	0.32	0.31	0.29
17	0.16	0.18	0.20	0.20	0.22	0.23	0.23	0.23	0.20	0.17
18	0.11	0.12	0.14	0.14	0.15	0.16	0.16	0.15	0.12	0.09
19	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.08	0.07	0.05
	To be subtracted from % water									
21	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
22	0.12	0.14	0.14	0.14	0.14	0.14	0.15	0.14	0.14	0.14
23	0.18	0.20	0.20	0.21	0.21	0.21	0.23	0.21	0.22	0.22
24	0.24	0.26	0.26	0.27	0.28	0.28	0.30	0.28	0.29	0.29
25	0.30	0.32	0.32	0.34	0.36	0.36	0.38	0.36	0.36	0.37
26	0.36	0.39	0.39	0.41	0.43	0.43	0.46	0.44	0.43	0.44
27	0.43	0.46	0.46	0.48	0.50	0.51	0.55	0.52*	0.50	0.51
28	0.50	0.53	0.53	0.55	0.58	0.59	0.63	0.60*	0.57	0.59
29	0.57	0.60	0.61	0.62	0.66	0.67	0.71	0.68*	0.65	0.67
30	0.64	0.67	0.70	0.71	0.74	0.75	0.80	0.76*	0.73	0.75
% H_2O	95	90	85	80	70	60	50	40	30	25

* These are corrected values. Stanek's original table gives values 0.10 higher.

TABLE FOR USE WITH ZEISS IMMERSION REFRACTOMETER (57.5) R = scale reading; % S = % sucrose

R	% S	R	% S	R	% S	R	% S	R	% S	R	% S	R	% S	R	% S
15.0	0.00	21.0	1.58	27.0	3.16	33.0	4.74	39.0	6.31	45.0	7.84	51.0	9.32	57.0	10.78
.1	.03	.1	.61	.1	.19	.1	.77	.1	.33	.1	.87	.1	.34	.1	.80
.2	.05	.2	.64	.2	.21	.2	.79	.2	.36	.2	.90	.2	.36	.2	.83
.3	.08	.3	.66	.3	.24	.3	.82	.3	.39	.3	.92	.3	.39	.3	.85
.4	.11	.4	.69	.4	.26	.4	.84	.4	.41	.4	.95	.4	.41	.4	.88
.5	.13	.5	.71	.5	.29	.5	.87	.5	.43	.5	.97	.5	.44	.5	.90
.6	.16	.6	.74	.6	.32	.6	.90	.6	.46	.6	8.00	.6	.46	.6	.92
.7	.19	.7	.77	.7	.34	.7	.92	.7	.49	.7	.03	.7	.49	.7	.95
.8	.21	.8	.79	.8	.37	.8	.95	.8	.51	.8	.05	.8	.51	.8	.97
.9	.24	.9	.82	.9	.40	.9	.98	.9	.54	.9	.07	.9	.53	.9	11.00
16.0	.26	22.0	.84	28.0	.42	34.0	5.00	40.0	.56	46.0	.10	52.0	.56	58.0	.03
.1	.29	.1	.87	.1	.45	.1	.03	.1	.59	.1	.12	.1	.58	.1	.05
.2	.32	.2	.90	.2	.48	.2	.05	.2	.61	.2	.15	.2	.60	.2	.07
.3	.34	.3	.92	.3	.50	.3	.08	.3	.64	.3	.17	.3	.63	.3	.10
.4	.37	.4	.95	.4	.53	.4	.11	.4	.66	.4	.19	.4	.66	.4	.12
.5	.40	.5	.98	.5	.56	.5	.13	.5	.69	.5	.22	.5	.68	.5	.15
.6	.42	.6	2.00	.6	.58	.6	.16	.6	.72	.6	.24	.6	.70	.6	.17
.7	.45	.7	.03	.7	.61	.7	.19	.7	.74	.7	.27	.7	.73	.7	.19
.8	.48	.8	.05	.8	.64	.8	.21	.8	.77	.8	.29	.8	.75	.8	.22
.9	.50	.9	.08	.9	.66	.9	.24	.9	.79	.9	.32	.9	.78	.9	.24
17.0	.53	23.0	.11	29.0	.69	35.0	.26	41.0	.82	47.0	.34	53.0	.80	59.0	.27
.1	.56	.1	.13	.1	.71	.1	.29	.1	.84	.1	.36	.1	.83	.1	.29
.2	.58	.2	.16	.2	.74	.2	.32	.2	.87	.2	.39	.2	.85	.2	.32
.3	.61	.3	.19	.3	.77	.3	.34	.3	.90	.3	.41	.3	.88	.3	.34
.4	.64	.4	.21	.4	.79	.4	.37	.4	.92	.4	.44	.4	.90	.4	.36
.5	.66	.5	.24	.5	.82	.5	.40	.5	.95	.5	.46	.5	.92	.5	.39
.6	.69	.6	.26	.6	.84	.6	.42	.6	.97	.6	.49	.6	.95	.6	.41
.7	.71	.7	.29	.7	.87	.7	.45	.7	7.00	.7	.51	.7	.97	.7	.44
.8	.74	.8	.32	.8	.90	.8	.48	.8	.03	.8	.53	.8	10.00	.8	.46
.9	.77	.9	.34	.9	.92	.9	.50	.9	.05	.9	.56	.9	.03	.9	.49
18.0	.79	24.0	.37	30.0	.95	36.0	.53	42.0	.08	48.0	.58	54.0	.05	60.0	.51
.1	.82	.1	.40	.1	.98	.1	.56	.1	.10	.1	.60	.1	.07	.1	.53
.2	.84	.2	.42	.2	4.00	.2	.58	.2	.13	.2	.63	.2	.10	.2	.56
.3	.87	.3	.45	.3	.03	.3	.61	.3	.15	.3	.66	.3	.12	.3	.58
.4	.90	.4	.48	.4	.05	.4	.64	.4	.18	.4	.68	.4	.15	.4	.60
.5	.92	.5	.50	.5	.08	.5	.66	.5	.20	.5	.70	.5	.17	.5	.63
.6	.95	.6	.53	.6	.11	.6	.69	.6	.23	.6	.73	.6	.19	.6	.66
.7	.98	.7	.56	.7	.13	.7	.71	.7	.26	.7	.75	.7	.22	.7	.68
.8	1.00	.8	.58	.8	.16	.8	.74	.8	.28	.8	.78	.8	.24	.8	.70
.9	.03	.9	.61	.9	.19	.9	.77	.9	.31	.9	.80	.9	.27	.9	.73
19.0	.05	25.0	.64	31.0	.21	37.0	.79	43.0	.33	49.0	.83	55.0	.29	61.0	.75
.1	.08	.1	.66	.1	.24	.1	.82	.1	.36	.1	.85	.1	.32	.1	.78
.2	.11	.2	.69	.2	.26	.2	.84	.2	.39	.2	.88	.2	.34	.2	.80
.3	.13	.3	.71	.3	.29	.3	.87	.3	.41	.3	.90	.3	.36	.3	.83
.4	.16	.4	.74	.4	.32	.4	.90	.4	.43	.4	.92	.4	.39	.4	.85
.5	.19	.5	.77	.5	.34	.5	.92	.5	.46	.5	.95	.5	.41	.5	.88
.6	.21	.6	.79	.6	.37	.6	.95	.6	.49	.6	.97	.6	.44	.6	.90
.7	.24	.7	.82	.7	.39	.7	.98	.7	.51	.7	9.00	.7	.46	.7	.92
.8	.26	.8	.84	.8	.42	.8	6.00	.8	.54	.8	.03	.8	.49	.8	.95
.9	.29	.9	.87	.9	.45	.9	.03	.9	.56	.9	.05	.9	.51	.9	.97
20.0	.32	26.0	.90	32.0	.48	38.0	.05	44.0	.59	50.0	.07	56.0	.53	62.0	12.00
.1	.34	.1	.92	.1	.50	.1	.08	.1	.61	.1	.10	.1	.56	.1	.03
.2	.37	.2	.95	.2	.53	.2	.10	.2	.64	.2	.12	.2	.58	.2	.05
.3	.40	.3	.98	.3	.56	.3	.13	.3	.66	.3	.15	.3	.60	.3	.07
.4	.42	.4	3.00	.4	.58	.4	.15	.4	.69	.4	.17	.4	.63	.4	.09
.5	.45	.5	.03	.5	.61	.5	.17	.5	.72	.5	.19	.5	.66	.5	.12
.6	.48	.6	.05	.6	.64	.6	.20	.6	.74	.6	.22	.6	.68	.6	.14
.7	.50	.7	.08	.7	.66	.7	.23	.7	.77	.7	.24	.7	.70	.7	.16
.8	.53	.8	.11	.8	.69	.8	.26	.8	.79	.8	.27	.8	.73	.8	.18
.9	.56	.9	.13	.9	.71	.9	.28	.9	.82	.9	.29	.9	.75	.9	.21

R	% S	R	% S	R	% S	R	% S	R	% S	R	% S	R	% S	R	% S
63.0	12.23	69.0	13.61	75.0	14.98	81.0	16.31	87.0	17.66	92.0	18.74	97.0	19.80	102.0	20.87
.1	.25	.1	.63	.1	15.00	.1	33	.1	.68	.1	.76	.1	.82	.1	.89
.2	.28	.2	.66	.2	.03	.2	.35	.2	.71	.2	.78	.2	.85	.2	.91
.3	.30	.3	.68	.3	.05	.3	.38	.3	.73	.3	.80	.3	.87	.3	.93
.4	.32	.4	.70	.4	.07	.4	.40	.4	.75	.4	.82	.4	.89	.4	.95
.5	.35	.5	.73	.5	.09	.5	.42	.5	.77	.5	.85	.5	.91	.5	.97
.6	.37	.6	.75	.6	.11	.6	.44	.6	.79	.6	.87	.6	.93	.6	21.00
.7	.39	.7	.77	.7	.13	.7	.47	.7	.82	.7	.89	.7	.95	.7	.02
.8	.42	.8	.79	.8	.16	.8	.49	.8	.84	.8	.91	.8	.97	.8	.04
.9	.44	.9	.82	.9	.18	.9	.51	.9	.86	.9	.93	.9	20.00	.9	.06
64.0	.46	70.0	.84	76.0	.20	82.0	.54	88.0	.89	93.0	.95	98.0	.02	103.0	.08
.1	.49	.1	.87	.1	.22	.1	.56	.1	.91	.1	.97	.1	.04	.1	.10
.2	.51	.2	.89	.2	.24	.2	.59	.2	.93	.2	19.00	.2	.06	.2	.13
.3	.53	.3	.92	.3	.26	.3	.61	.3	.95	.3	.02	.3	.08	.3	.15
.4	.56	.4	.94	.4	.28	.4	.63	.4	.98	.4	.04	.4	.10	.4	.17
.5	.58	.5	.96	.5	.30	.5	.65	.5	18.00	.5	.06	.5	.13	.5	.19
.6	.60	.6	.98	.6	.32	.6	.68	.6	.02	.6	.08	.6	.15	.6	.21
.7	.63	.7	14.00	.7	.34	.7	.70	.7	.04	.7	.10	.7	.17	.7	.23
.8	.65	.8	.03	.8	.36	.8	.72	.8	.06	.8	.13	.8	.19	.8	.25
.9	.67	.9	.05	.9	.38	.9	.74	.9	.08	.9	.15	.9	.21	.9	.27
65.0	.69	71.0	.07	77.0	.40	83.0	.76	89.0	.10	94.0	.17	99.0	.23	104.0	.29
.1	.72	.1	.09	.1	.42	.1	.79	.1	.13	.1	.19	.1	.25	.1	.31
.2	.74	.2	.11	.2	.44	.2	.81	.2	.15	.2	.21	.2	.27	.2	.34
.3	.76	.3	.14	.3	.47	.3	.83	.3	.17	.3	.23	.3	.29	.3	.36
.4	.79	.4	.16	.4	.49	.4	.85	.4	.19	.4	.25	.4	.31	.4	.38
.5	.81	.5	.18	.5	.51	.5	.88	.5	.21	.5	.27	.5	.34	.5	.40
.6	.83	.6	.20	.6	.54	.6	.90	.6	.23	.6	.29	.6	.36	.6	.42
.7	.86	.7	.23	.7	.56	.7	.92	.7	.25	.7	.31	.7	.38	.7	.44
.8	.88	.8	.25	.8	.59	.8	.95	.8	.27	.8	.34	.8	.40	.8	.47
.9	.90	.9	.27	.9	.61	.9	.97	.9	.29	.9	.36	.9	.42	.9	.49
66.0	.93	72.0	.29	78.0	.63	84.0	17.00	90.0	.31	95.0	.38	100.0	.44	105.0	.51
.1	.95	.1	.32	.1	.65	.1	.02	.1	.34	.1	.40	.1	.47	.1	.53
.2	.97	.2	.34	.2	.68	.2	.04	.2	.36	2	.42	.2	.49	.2	.55
.3	13.00	.3	.36	.3	.70	.3	.07	.3	.38	.3	.44	.3	.51	.3	.57
.4	.03	.4	.38	.4	.72	.4	.09	.4	.40	.4	.47	.4	.53	.4	.59
.5	.05	.5	.40	.5	.74	.5	.11	.5	.42	.5	.49	.5	.55	.5	.61
.6	.07	.6	.43	.6	.76	.6	.13	.6	.44	.6	.51	.6	.57	.6	.63
.7	.09	.7	.45	.7	.79	.7	.15	.7	.47	.7	.53	.7	.59	.7	.66
.8	.11	.8	.48	.8	.81	.8	.18	.8	.49	.8	.55	.8	.61	.8	.68
.9	.14	.9	.50	.9	.83	.9	.20	.9	.51	.9	.57	.9	.63	.9	.70
67.0	.16	73.0	.52	79.0	.85	85.0	.22	91.0	.53	96.0	.59	101.0	.66	106.0	.71
.1	.18	.1	.54	.1	.88	.1	.24	.1	.55	.1	.61	.1	.68		
.2	.20	.2	.57	.2	.90	.2	.27	.2	.57	.2	.63	.2	.70		
.3	.23	.3	.59	.3	.92	.3	.29	.3	.59	.3	.66	.3	.72		
.4	.25	.4	.61	.4	.95	.4	.31	.4	.61	.4	.68	.4	.74		
.5	.27	.5	.63	.5	.97	.5	.33	.5	.63	.5	.70	.5	.76		
.6	.29	.6	.66	.6	16.00	.6	.35	.6	.66	.6	.72	.6	.78		
.7	.32	.7	.68	.7	.03	.7	.38	.7	.68	.7	.74	.7	.80		
.8	.34	.8	.70	.8	.05	.8	.40	.8	.70	.8	.76	.8	.82		
.9	.36	.9	.73	.9	.07	.9	.42	.9	.72	.9	.78	.9	.85		
68.0	.38	74.0	.75	80.0	.09	86.0	.44								
.1	.40	.1	.77	.1	.11	.1	.47								
.2	.43	.2	.79	.2	.13	.2	.49								
.3	.45	.3	.82	.3	.16	.3	.51								
.4	.48	.4	.84	.4	.18	.4	.53								
.5	.50	.5	.87	.5	.20	.5	.55								
.6	.52	.6	.89	.6	.22	.6	.58								
.7	.54	.7	.92	.7	.24	.7	.60								
.8	.57	.8	.94	.8	.27	.8	.62								
.9	.59	.9	.96	.9	.29	.9	.64								

Dry Substance (D) in Sugar-House Products at 28°C ([76])

n_D^{28}	% D	Decimals	
1.3335	1	0.0001 = 0.05	0.0010 = 0.75
1.3349	2	0.0002 = 0.1	0.0011 = 0.8
1.3364	3	0.0003 = 0.2	0.0012 = 0.8
1.3379	4	0.0004 = 0.25	0.0013 = 0.85
1.3394	5	0.0005 = 0.3	0.0014 = 0.9
1.3409	6	0.0006 = 0.4	0.0015 = 1.0
1.3424	7	0.0007 = 0.5	
1.3439	8	0.0008 = 0.6	
1.3454	9	0.0009 = 0.7	
1.3469	10		
1.3484	11	0.0001 = 0.05	
1.3500	12	0.0002 = 0.1	
1.3516	13	0.0003 = 0.2	
1.3530	14	0.0004 = 0.25	
1.3546	15	0.0005 = 0.3	
1.3562	16	0.0006 = 0.4	
1.3578	17	0.0007 = 0.45	
1.3594	18	0.0008 = 0.5	
1.3611	19	0.0009 = 0.6	
1.3627	20	0.0010 = 0.65	
1.3644	21	0.0011 = 0.7	
1.3661	22	0.0012 = 0.75	
1.3678	23	0.0013 = 0.8	
1.3695	24	0.0014 = 0.85	
1.3712	25	0.0015 = 0.9	
1.3729	26	0.0016 = 0.95	
1.3746	27		
1.3764	28		
1.3782	29	0.0001 = 0.05	0.0012 = 0.6
1.3800	30	0.0002 = 0.1	0.0013 = 0.65
1.3818	31	0.0003 = 0.15	0.0014 = 0.7
1.3836	32	0.0004 = 0.2	0.0015 = 0.75
1.3854	33	0.0005 = 0.25	0.0016 = 0.8
1.3872	34	0.0006 = 0.3	0.0017 = 0.85
1.3890	35	0.0007 = 0.35	0.0018 = 0.9
1.3909	36	0.0008 = 0.4	0.0019 = 0.95
1.3928	37	0.0009 = 0.45	0.0020 = 1.0
1.3947	38	0.0010 = 0.5	0.0021 = 1.0
1.3966	39	0.0011 = 0.55	
1.3984	40		
1.4003	41		
1.4023	42		
1.4043	43	0.0001 = 0.05	0.0012 = 0.6
1.4063	44	0.0002 = 0.1	0.0013 = 0.65
1.4083	45	0.0003 = 0.15	0.0014 = 0.7
1.4104	46	0.0004 = 0.2	0.0015 = 0.75
1.4124	47	0.0005 = 0.25	0.0016 = 0.8
1.4145	48	0.0006 = 0.3	0.0017 = 0.85
1.4166	49	0.0007 = 0.35	0.0018 = 0.9
1.4186	50	0.0008 = 0.4	0.0019 = 0.95
1.4207	51	0.0009 = 0.45	0.0020 = 1.0
1.4228	52	0.0010 = 0.5	0.0021 = 1.0
1.4249	53	0.0011 = 0.55	
1.4270	54		
1.4292	55	0.0001 = 0.05	0.0013 = 0.55
1.4314	56	0.0002 = 0.1	0.0014 = 0.6
1.4337	57	0.0003 = 0.1	0.0015 = 0.65
1.4359	58	0.0004 = 0.15	0.0016 = 0.7
1.4382	59	0.0005 = 0.2	0.0017 = 0.75
1.4405	60	0.0006 = 0.25	0.0018 = 0.8
1.4428	61	0.0007 = 0.3	0.0019 = 0.85
1.4451	62	0.0008 = 0.35	0.0020 = 0.9
1.4474	63	0.0009 = 0.4	0.0021 = 0.9

Dry Substance (D) in Sugar-House Products at 28°C ([76]).—(*Continued*)

n_D^{28}	% D	Decimals	
1.4497	64	0.0010 = 0.45	0.0022 = 0.95
1.4520	65	0.0011 = 0.5	0.0023 = 1.0
1.4543	66	0.0012 = 0.5	0.0024 = 1.0
1.4567	67		
1.4591	68		
1.4615	69		
1.4639	70		
1.4663	71		
1.4687	72		
1.4711	73		
1.4736	74		
1.4761	75	0.0001 = 0.0	0.0015 = 0.55
1.4786	76	0.0002 = 0.05	0.0016 = 0.6
1.4811	77	0.0003 = 0.1	0.0017 = 0.65
1.4836	78	0.0004 = 0.15	0.0018 = 0.65
1.4862	79	0.0005 = 0.2	0.0019 = 0.7
1.4888	80	0.0006 = 0.2	0.0020 = 0.75
1.4914	81	0.0007 = 0.25	0.0021 = 0.8
1.4940	82	0.0008 = 0.3	0.0022 = 0.8
1.4966	83	0.0009 = 0.35	0.0023 = 0.85
1.4992	84	0.0010 = 0.35	0.0024 = 0.9
1.5019	85	0.0011 = 0.4	0.0025 = 0.9
1.5046	86	0.0012 = 0.45	0.0026 = 0.95
1.5073	87	0.0013 = 0.5	0.0027 = 1.0
1.5100	88	0.0014 = 0.5	0.0028 = 1.0
1.5127	89		
1.5155	90		

Corrections for the Temperature ([76])

% D / °C	Dry substance												
	0	5	10	15	20	25	30	40	50	60	70	80	90
	Subtract												
20	0.53	0.54	0.55	0.56	0.57	0.58	0.60	0.62	0.64	0.62	0.61	0.60	0.58
21	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50
22	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44
23	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38
24	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30
25	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22
26	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14
27	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07
	Add												
29	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07
30	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14
31	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22
32	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30
33	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38
34	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44
35	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50

Density of Aqueous Sucrose Solutions at 20°C, g/ml

All weights *in vacuo*. For hydrometer conversion formulae *see* vol. I, p. 31 and for computed conversion tables and temperature corrections *v.* ([17,5, 61,5, 75]). For conversion table giving deg. Brix, d_4^{20}, d_{20}^{20} and deg. Baumé, based upon the formula, °Bé = 145 − 145/sp. gr., d_{20}^{20} *v.* ([7]).

DENSITY OF AQUEOUS SUCROSE SOLUTIONS AT 20°C, g/ml.

% sucrose	d_4^{20}									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051933	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055325	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095782	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106786	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114229	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166269	1.166775	1.167281	1.167786	1.168293	1.168880	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018

Density of Aqueous Sucrose Solutions at 20°C, g/ml.—(*Continued*)

% sucrose	d_4^{20} 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246234	1.246795	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273035	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295911	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300079	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306068	1.306669	1.307271	1.307872	1.308475	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312699	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335342	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342798	1.343421	1.344046	1.344671	1.345296	1.345922	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353456	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363590	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378326
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.403452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408398	1.409061	1.409723	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422390	1.423059	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460495	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275

Solubility

Solubility of Sucrose in Water (32)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
0	64.18	10	65.58	19	66.93	28	68.37
1	64.31	11	6-.73	20	67.09	29	68.53
2	64.45	12	65.88	21	67.25	30	68.70
3	64.59	13	66.03	22	67.41	31	68.87
4	64.73	14	66.18	23	67.57	32	69.04
5	64.87	15	66.33	24	67.73	33	69.21
6	65.01	16	66.48	25	67.89	34	69.38
7	65.15	17	66.63	26	68.05	35	69.55
8	65.29	18	66.78	27	68.21	36	69.72
9	65.43						

Solubility of Sucrose in Water (32).—(*Continued*)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
37	69.89	49	72.06	61	74.38	73	76.85
38	70.06	50	72.25	62	74.58	74	77.06
39	70.24	51	72.44	63	74.78	75	77.27
40	70.42	52	72.63	64	74.98	76	77.48
41	70.60	53	72.82	65	75.18	77	77.70
42	70.78	54	73.01	66	75.38	78	77.92
43	70.96	55	73.20	67	75.59	79	78.14
44	71.14	56	73.39	68	75.80	80	78.36
45	71.32	57	73.58	69	76.01	81	78.58
46	71.50	58	73.78	70	76.22	82	78.80
47	71.68	59	73.98	71	76.43	83	79.02
48	71.87	60	74.18	72	76.64	84	79.24

SOLUBILITY OF SUCROSE IN WATER (32).—(*Continued*)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
85	79.46	89	80.38	93	81.30	97	82.25
86	79.69	90	80.61	94	81.53	98	82.49
87	79.92	91	80.84	95	81.77	99	82.73
88	80.15	92	81.07	96	82.01	100	82.97

FREEZING POINT-SOLUBILITY DATA (64)

System $C_{12}H_{22}O_{11}$-H_2O, E = eutectic, m = metastable

°C	g/100 g H_2O	°C	g/100 g H_2O
Ice		Ice + $C_{12}H_{22}O_{11}$	
± 0.0	0.0	−13.9 E	166.0
− 4.03	60.0	$C_{12}H_{22}O_{11}$	
−10.42	130.0	+ 0.9	180.5
−12.68	150.0	+15.8	196.0
−13.68	164.0	+25.6	210.5
−17.08 m	200.0	+30.5	218.0

SOLUBILITY OF SUCROSE IN AQUEOUS METHYL ALCOHOL AT 15°C (31)

Vol. %CH_3OH in solvent	100	90	80
g sucrose per 100 cm³ solution	0.3	1.6	3.8

Hydrolysis

HYDROLYSIS (INVERSION) OF SUCROSE

Sucrose	Acid	°C	k	Lit.
17.1%	0.099N HCl	35	0.00161	(72)

1000 g H_2O + 0.25 g-mole of sucrose + 1 g-mole of acid, 25°C

HNO_3	HCl	H_2SO_4	Lit.
k = 0.00464	0.00500	0.00549	(1)

TIME NECESSARY FOR VARYING PERCENTAGES OF HYDROLYSIS (INVERSION) OF SUCROSE WITH HCL (0.01N at 20°C) AS THE CATALYZER (50)

°C	k	50% inversion, min	90% inversion, min	99.9% inversion, hr
50	0.001145	262.9	873.4	43.5
60	0.003806	79.1	262.9	13.1
70	0.01182	25.5	84.6	4.2
80	0.03303	9.11	30.3	1.5
90	0.08922	3.37	11.21	33.4*
100	0.26797	1.12	3.73	11.2*

* Minutes.

The reaction velocities for lower acidities may be computed without appreciable error by considering the velocity proportional to the concentration of acid. Thus, the velocities at 0.005N HCl will be very closely half those at 0.01N and the time of reaction twice as great.

REACTION VELOCITIES AT VARIOUS TEMPERATURES

$$k = \frac{1}{t} \log_{10} \frac{r_0 - r}{r_t - r},\ t \text{ in min}$$

$$k_{T_2} = k_{T_1} e^x, \text{ where } x = \frac{Q}{R} \frac{T_2 - T_1}{T_2 T_1}$$

Sucrose, 50%; HCl, 0.1N at 20°C. Q/R = 12 925.2 (48)

°C	k	°C	k
0	0.0000077	59.903	0.04003
15.098	0.000092	69.974	0.1236
30.000	(0.0008732)	80.130	0.3687
39.916	0.00334	90.292	1.033
49.840	(0.01206)	90.316	1.020

Sucrose, 50%; HCl, 0.01N at 20°C. Q/R = 12 940.05 (48)

°C	k	°C	k
30.00	0.0008148	69.97	0.01194
49.85	0.001122	80.10	0.03429
59.90	0.003766	90.30	0.0939

Sucrose, 60%; HCl, 0.7925N at 20°C. Q/R = 13 087.6 (48)

°C	k	°C	k
20	0.002156	35.072	0.01882
30.117	0.00983	40.078	0.03780
30.093	0.01001	40.088	0.03791

INVERSION OF SUCROSE WITH INVERTASE (69)

$t = \frac{1}{n} \log_{10} \frac{100}{100 - p} + 0.002642p - 0.000008860p^2 - 0.0000001034\,p^3$; t = minutes; p = % inversion; n is proportional to the amount of active invertase and depends upon the temperature.

Range of invertase concentration from 12 to 1; temperature from 15 to 35°; H-ion concentration 4×10^{-5} to 3.2×10^{-7}.

At any given temperature n may be used to measure the activity of an invertase solution.

LENGTH OF TIME REQUIRED TO FORM CARAMEL EQUIVALENT TO 0.01 % INVERT SUGAR (9)

The time, in hours, required to form caramel equivalent to 0.01% invert sugar at any temperature t (°C) between 39 and 100° may be computed from the equation:

$$\log_{10} \text{hr} = 5.0026 - 0.0595t.$$

LACTOSE

$C_{12}H_{22}O_{11}$ (Galactose < Dextrose <)

TRANSITION TEMPERATURES AND MELTING POINTS (85)

α-hydrate → β-anhydrous, 93.5°. α-anhydrous → liquid, 222.8°. β-anhydrous → liquid, 252.2°. α-anhydrous is metastable below its melting point. α-hydrate → liquid, 201.6°.

Optical Rotation

IN H_2O

$[\alpha]_D^t = 52.4_2 + 0.072\,(20° - t)$; 5 g/100 ml (4); $[\alpha]_{546.1}^t = 61.9_4 + 0.085\,(20° - t)$; 5 g/100 ml (4); $[\alpha]_D^{20} = 52.53$ (21); $[\alpha]_{546}^{25} = 61.36$; $[\alpha]_{589}^{25} = 51.90$ (78).

ROTATION DISPERSION AT EQUILIBRIUM (30)

Values of $[\alpha]_\lambda^{20}$; C = g hydrate/100 ml

λ	H_2O, C = 2	Pyridine, C = 0.5	Formic acid, C = 5.9
656	39.82	31.00	78.64
589	52.42	41.33	97.76
535	62.09	49.66	117.92
508	72.25	60.00	134.38
479	83.25	73.66	160.79
447	98.17	91.66	180.92

$[\alpha]_D$ IN VARIOUS SOLVENTS

Solvent	Anhydrous lactose, g/100 ml	°C	$[\alpha]_D^t$ α	$[\alpha]_D^t$ α ⇄ β	$[\alpha]_D^t$ β	$10^3(k_1 + k_2)$	Lit.
H_2O	2.316	14	84.4	55.25		3.78	(60)
Formamide	2.27	15	82.4	51.2		0.387	(60)
H_2O	2.75	17		55.23	35.97	2.97	(60)
Formamide	1.85	17		51.22	29.11	0.4	(60)
H_2O		20	86.		34.5		(38)
H_2O		20	90.0	55.3	35.0	4.65	(44)
40%, C_2H_5OH		20	81.0	55.3	33.0		(44)
H_2O		0				0.5	(35)

$d[\alpha]_D/dt = -0.08$ between t = 10 − 25°C (60).

Effect of H_2SO_4 (11)

N = normality

N, H_2SO_4	0	10	12	14	16	18	20	22	24	26
$[\alpha]^{25}_D$	52.5	56.7	59.0	61.5	63.5	65.5*	68.5	72.5	76.0	99.0

* Noticeable inversion begins.

Refractive Index and Density of Aqueous Solutions (77)

% anhydrous lactose	23.38	17.06	11.66	5.80	2.78	1.28
d^{25}_4	1.0969	1.0681	1.0448	1.0204	1.0092	1.0018
n^{25}_D	1.3716	1.3605	1.3517	1.3423	1.3380	1.3350

Solubility

Solubility in Water (38)

S_0 = initial, S_∞ = final solubility in millimoles of anhydrous lactose per 100 g H_2O

(*a*) Solid phase: the hydrate

°C	0.0	15.0	25.0	39.0	49.0	64.0	74.0	89.0
S_∞	34.8	49.7	63.4	92.7	124.0	193.0	253.0	407.0
S_0	14.8	20.9	25.3	37.0*	52.0*	77.0*	101.0*	163.0*

(*b*) Solid phase: β-anhydrous. Final solubility: at 0°, 42.9; at 100°, 61.2 wt. % anhydrous

(*c*) Solid phase: β-anhydrous

°C	0.0	0.0	100
S_0	132	(124) (extrap.)	227
S_∞	220		461

* Calculated from final solubility and equilibrium ratio.

Per Cent β-anhydrous at Equilibrium in a Solution Saturated with the Hydrate (38)

°C	0	15	25	39	49	64	74	89
%	5.8	7.7	9.6	14.0	18.0	24.0	27.0	35.0

Per cent hydrate at equilibrium in solution saturated with the β-anhydrous = 17 at 0°C; = 24 at 100°C (38).

Solubility in Aqueous C_2H_5OH (44)

g anhydrous lactose in 100 cm³ 40% C_2H_5OH at 20°C = 1.1 initial; = 2.4 final.

Solubility and Freezing Point Lowering

Solubility in H_2O. Solid phase: lactose hydrate

°C	% lac.	Lit.	°C	% lac.	Lit.	°C	% lac.	Lit.
0	10.6	(39)	57.1	34.9	(28)	100	60.5	(39)
15	14.4	(39)	63.9	39.1	(28)	107.0	63.9	(28)
21.5	16.7	(79)	64.0	39.7	(39)	121.5	69.4	(28)
25	17.8	(39)	73.5	45.8	(28)	133.6	73.2	(28)
28	19.4	(79)	74.0	46.2	(39)	138.8	75.2	(28)
38	23.5	(79)	79.1	49.6	(28)	158.8	81.1	(28)
39	24.0	(39)	87.2	55.1	(28)	178.8	86.7	(28)
49	29.7	(39)	88.2	56.0	(28)	200	92.5	(27)

Freezing Point Lowering (38, 58)

Between 1 and 30 millimoles lactose per 100 g H_2O the molal lowering is 1.86°/mole and at 48 millimoles 1.89°/mole.

Cryohydrate Points.—Initial, −0.279° and 14.8 millimoles per 100 g H_2O; final for hydrate, −0.65°; initial for β-anhydrous, −2.3°; final for β-anhydrous, −4.1°.

Mutarotation

Mutarotation in H_2O

°C	0.0	15.0	25.0	0	14.0	17.0	20.0
$10^3 (k_1 + k_2)$	0.51	2.97	7.92		3.78	2.97	6.2
$10^3 k_1$	0.29	1.55	4.65	0.24			
$10^3 k_2$	0.21	1.08	3.08				
Lit.	(35)	(35)	(35)	(38)	(60)	(60)	(11)

Composition of an Aqueous Solution at Equilibrium (27)

°C	0	25	50	75	92	100
% β/% α	1.65	1.58	1.51	1.45	1.39	1.33

Hydrolysis (10)

$$k_H = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty} \quad t \text{ in min}$$

Anhydrous lactose, g/l	Acid	$10^3 k_H$	°C
50	22N H_2SO_4	4.4	20
50	24N H_2SO_4	7.7	20
80	HCl, d = 1.185	1.1	15
80	HCl, d = 1.185	2.1	20
80	HCl, d = 1.185	4.3	25
80	HCl, d = 1.185	8.2	30
80	HCl, d = 1.185	17.1	35
80	HCl, d = 1.185	35.2	40
40	HCl, d = 1.185	5.1	25
120	HCl, d = 1.185	3.4	25
200	HCl, d = 1.185	1.5	25
80	$HClO_4$, d = 1.67	24.2	20
	$HClO_4$, d = 1.67	50.0	25

$C_{12}H_{22}O_{11}$, MALTOSE

Composition: (Glucose < Glucose <)

Optical Rotation

In H_2O (21)

$[\alpha]^{20}_D = 138.475 - 0.01837p$ for values of p from 5 to 35 wt. % *in vacuo*. $\alpha]^{25}_{546} = 153.75$. $[\alpha]^{25}_{589} = 131.25$ (78).

In Various Solvents at 20°C

Solvent	Maltose, g/100 ml	$[\alpha]^{20}_D$ α	$\alpha \rightleftarrows \beta$	β	$10^3(k_1 + k_2)$	Lit.
H_2O		168*	136.0	118.0	7.2	(44)
60% C_2H_5OH		158*	128.1	111.0		(44)
H_2O	2.52		136.2	123	5.03	(61)
Formamide	2.12		130.3	113	1.63	(61)
H_2O			137	119		(39)
H_2O			137			(81)
Pyridine			122.0			(81)
H_2O			137			(30)
Pyridine			124			(30)
Formic acid			175			(30)

* Calculated.

Effect of Pyridine

Two g maltose in 200 cm³ of a 5% aqueous pyridine solution (34)

After, days	0	1	2	After heating for, hr	0	0.5	1.5
R, °arc	6.75	6.70		R, °arc	6.7	5.6	4.8

Effect of H_2SO_4

Maltose 5 g/100 ml (11)

N of H_2SO_4	0	10	12	18	22
$[\alpha]^{25}_D$	135.5	129.0	127.5	129.5	132.0

Equilibrium Rotation

Values of $[\alpha]_{\lambda}^{20}$ for $\alpha \rightleftarrows \beta$ in various solvents; maltose < 5 g/100 ml (30)

λ, mμ	656	589	535	508	479	447
H_2O	111	137	167	180	229	236
Pyridine	100	124	152	180	212	231
Formic acid	140	175	210	248	292	320

Refractive Index and Density of Aqueous Solutions (77)

% anhydrous maltose	19.40	9.60	4.77	2.32	1.16
d_4^{25}	1.0777	1.0362	1.0160	1.0064	1.0017
n_D^{25}	1.3639	1.3482	1.3406	1.3368	1.3354

Solubility

In H_2O (29)

°C	0.6	21.0	29.6	34.4	43.5	49.4
% M.	36.1	44.1	48.0	49.6	55.3	58.3
°C	54.2	59.8	66.3	74.2	87.0	96.5
% M.	60.2	63.7	66.7	72.3	79.3	85.1

In 60% C_2H_5OH at 20°C (44)

Initial, 3.0; final 4.75, g/100 cm³ of solution. Equilibrium mixture contains 64% β and 36% α.

Freezing Point Lowering (29)

In H_2O	% anhydrous maltose	24.0	16.7	12.4	7.16 (58)
	Δt_F, °C	1.87	1.16	0.79	0.395
In 0.1N NH_4OH aq. soln.	% anhydrous maltose	25.1	18.3	28.9	16.9
	Δt_F, °C	1.94	1.25	2.44	1.17

$C_6H_{12}O_6$, DEXTROSE (*d*-Glucose)

Optical Rotation

The saccharimetric normal weight for dextrose is 32.231 g (in air, $d = 0.0012$, brass weights) (47).

Rotations for λ = 546.1 mμ, 20°C; 200 mm Tube; Aqueous Solution

Saccharimetric normality	1	4/5	3/5	2/5	1/5
R, °arc	40.897	32.574_5	24.328	16.142	8.042

Corrections to Be Added to Saccharimetric Readings of Dextrose Solutions (47)

°S	Corr.	°S	Corr.	°S	Corr.
100	0	65	0.50	30	0.46
95	0.10	60	0.52	25	0.41
90	0.20	55	0.54	20	0.35
85	0.28	50	0.55	15	0.28
80	0.35	45	0.54	10	0.20
75	0.41	40	0.53	5	0.10
70	0.46	35	0.50	2	0.05

Specific Rotatory Power in H_2O

$[\alpha]_{546.1}^{20} = 62.032 + 0.04257\,C$; $= 62.032 + 0.0422\,p + 0.0001897\,p^2$. Valid from $C = 6$ to 32 g/100 ml soln. p = wt. %. All weights *in vacuo* (47). $[\alpha]_D^{20} = 52.50 + 0.0188p + 0.000517p^2$. Valid from $p = 0$ to 35 wt. %. All weights *in vacuo* (21, 89). $\alpha]_{546}^{25} = 62.02$; $[\alpha]_{589}^{25} = 52.48$ (78).

In Water, in Pyridine and in Formic Acid

Values of $[\alpha]_{\lambda}^{20}$ (30)

λ	In H_2O, 1/4 to 1/32 N	In pyridine, 1/4 N	In formic acid
656	41.47	60.87	96.0
589	52.52	75.64	122.8
535	64.90	93.55	150.0
508	73.03	104.00	176
479	83.05	118.02	203
447	95.79	136.90	224

In Various Solvents at 20°C

Solvent	Dextrose, g/100 ml	$[\alpha]_D^{20}$ α	$[\alpha]_D^{20}$ $\alpha \rightleftarrows \beta$	$[\alpha]_D^{20}$ β	$10^3 (k_1 + k_2)$	Lit.
H_2O	9.1	108.5	52.2		6.27	(60)
Formamide	2.5	122.7	57.27		1.09	(60)
H_2O	2.3		52.02	20.76	6.9	(61)
Formamide	1.7		56.28	15.74	0.996	(61)
H_2O		113.4	52.2	19.7		(44)
80% C_2H_5OH		115.2	59.0	20.3		(44)
C_2H_5OH		121.5	70.45	16.5		(44)
Pyridine			75.56			(30)
Formic acid			122.8			(30)

Effect of Propyl Alcohol

Alcohol used had $d_4^{19} = 0.810$. Dextrose concn. < 50 g/l (26)

Alc., g/l	100	200	300	400	500	600	700
$[\alpha]_D^{19}$	52.20	52.81	53.22	53.48	55.35	55.44	56.81

Effect of Salts (66)

Salt	$[\alpha]_D^{20}$	Salt	$[\alpha]_D^{20}$
Nil	**52.8**	2N NH_4Cl	52.3
4N KI	47.4	2N CH_3COONH_4	52.3
4N KBr	48.5	N CH_3COOK	52.3
4N KCl	49.6	4N $MgCl_2$	52.8
4N NH_4NO_3	50.6	N $MgCl_2$	52.8
2N KNO_3	50.6	2N $MgSO_4$	52.8
4N NH_4Cl	51.2	2N CH_3COONa	52.8
2N KCl	51.2	N CH_3COONa	52.8
N K_2SO_4	51.2	N CH_3COONH_4	52.8
2N $(NH_4)_2SO_4$	51.7	2N $BaCl_2$	54.7
2N CH_3COOK	51.7	3N $BaCl_2$	55.5
4N $NaNO_3$	52.3	2N $CaCl_2$	56.0
2N Na_2SO_4	52.3	4N $CaCl_2$	61.2

Effect of HCl (97)

Dextrose concn., 5 g/100 ml

% HCl	3.65	19.25	30.4	34.4	37.6	39.9	41.4	44.5
$[\alpha]_D^{16-17}$	+54.5	57.2	61.0	67.0	82.5	97.5	106.0	164.6

% HCl	0	42.0	46.6	46.7
°C	8	8	−12	−12
$[\alpha]_D^t$	52.2	113.3	200.0	202.0

Effect of H_2SO_4 (11)

Dextrose concn. = 50 g/l at 25°. The table gives values of $[\alpha]_D^{25}$ in acid of the normality stated. In acid above 22N, mutarotation is found. At 20°, 50 g/l in 24N acid gives $k = 0.0020$.

0	10N	16N	18N	20N	22N	24N	26N	28N
52.8	56.0	62.5	65.0	67.5	72.5	80.0	91.0	107.0

Refractive Index and Density of Aqueous Solutions (77)

% wt.	24.03	20.14	15.72	10.20	4.36	2.11	1.00
d_4^{25}	1.0962	1.0795	1.0604	1.0370	1.0146	1.0051	1.0007
n_D^{25}	1.3710	1.3646	1.3575	1.3486	1.3401	1.3366	1.3351

Density of Aqueous Solutions (47)

$d_4^{20} = 0.99840 + 0.003788\,p + 0.00001412p^2$. Range of p, 4 to 30, wt. % dextrose. All weights *in vacuo*.

Solubility

System: Dextrose-Water (49); *v.* Fig. 2

The solid curves show the final equilibria with respect to the solid phases, ice, dextrose hydrate, and anhydrous dextrose. The dotted curve shows the instantaneous solubility before mutarotation. All data are expressed in terms of anhydrous dextrose.

System: Dextrose-Ethyl Alcohol-(Water), 20°C

S_0 (resp. S_∞) = initial (resp. final) solubility, g anhyd. dextrose per liter of solution (44)

% wt., C_2H_5OH	α-anhydrous S_0	α-anhydrous S_∞	α-hydrate S_0	α-hydrate S	β-anhydrous S_0	β-anhydrous S_∞
80	20	45	13	30	49	91
100	8.5	16				

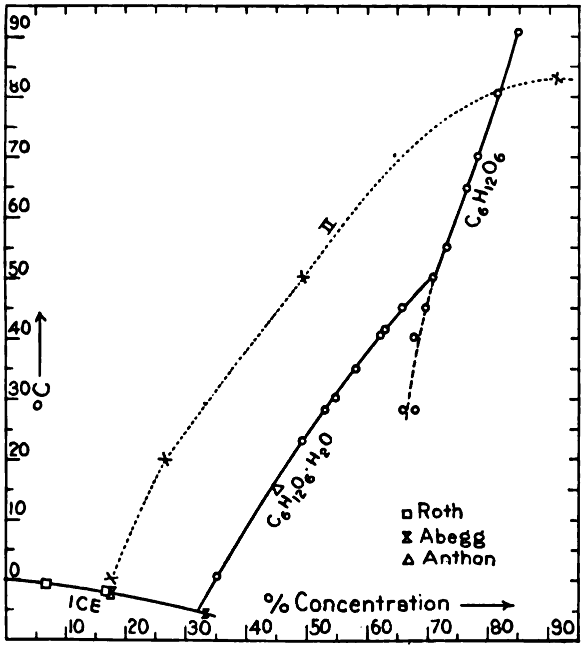


Fig. 2.

Mutarotation

Mutarotation at 20°C (24)

B = moles buffer per l solution

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
B = 0.1		B = 0.1		B = 0.01		B = 0.05	
4.88	13.0	3.08	7.7	4.96	7.28	4.87	10.7
4.28	9.0	2.66	8.1	3.43	6.74	B = 0.2	
4.08	8.7	2.04	9.5	2.54	7.20	4.80	17.9
3.44	7.8	1.02	20.0	1.75	8.72	B = 0	
						4.93	7.22

Variation of pH with Temperature and Concentration of Dextrose (68)

$[\alpha]_D$ = +111.2 for α-form; = +17.5 for β-form; = 52.5 for equilibrium mixture; at all temperatures and concentrations used

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
α-form, 0.15°C		37°C		6.50	34.3	6.43	0.78
1.33	2.42	1.0	118.6	6.55	33.0	6.70	0.80
2.38	0.91	1.72	50.0	6.75	51.7	7.51	1.86
3.05	0.79	2.06	37.6	7.27	86.7	8.00	3.30
3.98	0.79	2.53	32.6	7.55	118.1	37°C	
5.07	0.77	2.73	32.0	8.50	220.5	1.72	48.6
5.35	0.77	3.36	30.0	β-form, 0.15°C		2.60	31.3
6.84	0.92	3.99	29.9	1.33	2.10	2.92	30.0
7.51	2.2	5.58	30.5	2.02	0.93	4.82	30.0
		5.95	29.8	4.80	0.78	5.90	30.4
		6.37	32.2	6.00	0.76	6.30	32.5

$k_1 + k_2 = 0.0096 + 0.258[H^+] + 9750[OH^-]$ at 25° (36)

HCl, m/l....	0.0	0.001	0.005	0.01	0.03	0.06	0.10	t, °C
$10^3 (k_1 + k_2)$.	10.6	9.8	11.2	12.1	16.9	25.3	35.4	24.7

$k_1 + k_2 = 0.0167 + 0.44[H^+]$ at 30° in HCl solutions (37)

HCl, m/l........	0.0	0.0 + invertase	0.5	0.10	0.20
$10^3 (k_1 + k_2)$....	16.7	16.7	38.3	62.0	10.5

Mutarotation at 5.4°C (25)

Minimum rate occurs at pH = 5.0 which corresponds to a dissociation constant for dextrose of 5×10^{-18}. An average value for Q is 17 500

Form	Reagent	pH	$10^3 (k_1 + k_2)$
α	1.3N HCl....................	−0.08	108.6
β	1.3N HCl....................	−0.06	107.2
α	0.3N HCl....................	+0.54	14.38
α	0.1N HCl....................	1.05	4.35
β	0.1N HCl....................	1.06	4.14
α	0.03N HCl...................	1.52	2.26
α	0.01N HCl...................	1.98	1.61
β	0.01N HCl...................	1.99	1.55
α	0.002N HCl..................	2.74	1.38
β	0.045N HCl..................	5.13	1.19
α	0.001N $NaHCO_3$..............	7.34	1.33
β	0.003N $NaHCO_3$..............	7.84	1.46
α	0.01N $NaHCO_3$...............	8.14	1.56
β	0.01N $NaHCO_3$...............	8.25	1.90
β	0.0015N Na_2CO_3.............	9.13	7.82
α	0.003N Na_2CO_3..............	9.41	12.48
α	0.01N Na_2CO_3...............	10.07	41.10
β	0.01N Na_2CO_3...............	10.11	41.75
α	0.003N NaOH.................	10.41	83.76

Variation with Concentration and Temperature. Aqueous Solutions (42)

g/100 ml	$10^3 (k_1 + k_2)$25°C	Dextrose < 100 g/l °C	$10^3 (k_1 + k_2)$ α	$10^3 (k_1 + k_2)$ β
3	10.50			
3	10.57			
3	10.68	0.7	0.74	0.74
6	10.48	5	1.29	1.50
9.6	10.59	10	2.25	2.23
16	11.04	15	3.99	3.79
25	11.35	20	6.35	6.54
32	10.68	25	10.50	10.57
37	10.60	30	1.75	1.68
52	10.08	40	4.37	3.95
64	9.31			

$\log_{10} (k_1 + k_2) = 11.0198 - 3873/T$.

Mutarotation in Methyl Alcohol (5)

Concentration dextrose *ca.* 12.3 g/l

CH_3OH Time, hr	CH_3OH $[\alpha]_D^{44.8}$	CH_3OH + 0.5% H_2O Time, hr	CH_3OH + 0.5% H_2O $[\alpha]_D^{44.8}$	CH_3OH + 1% H_2O Time, hr	CH_3OH + 1% H_2O $[\alpha]_D^{44.8}$	CH_3OH + 2% H_2O Time, hr	CH_3OH + 2% H_2O $[\alpha]_D^{44.8}$
0.25	111.2	0.28	111.5	0.28	109.6	0.28	110.9
.43	110.0	.72	105.2	.53	106.9	.52	107.5
.83	106.3	1.32	102.4	.88	104.3	.77	105.2
1.38	104.8	1.63	98.5	1.47	99.2	1.13	99.9
2.63	97.7	2.22	96.9	1.92	95.9	1.82	90.1
4.05	88.4	3.22	91.0	3.22	85.8	2.33	85.9
5.53	83.2	4.00	86.9	4.33	81.7	3.42	79.5
6.83	79.5	5.85	80.5	5.88	74.8	4.22	76.9
		6.92	76.8	8.08	69.7	5.38	72.6
		8.38	73.1	11.42	66.7	6.75	69.7

Mutarotation in Methyl Alcohol (5).—(*Continued*)

CH_3OH		CH_3OH + 0.5% H_2O		CH_3OH + 1% H_2O		CH_3OH + 2% H_2O	
Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$
		12.05	69.9	24.0	64.0	8.93	66.1
		23.18	64.5			11.58	64.1
		25.08	64.5			24.25	64.1

Mutarotation in Ethyl Alcohol of Varying Concentrations at 20°C (44)

% C_2H_5OH	0	20	40	60	70	80
$10^3\ (k_1 + k_2)$	6.5	4.8	3.0	1.82	1.56	1.14

$C_6H_{12}O_6$, LEVULOSE

Optical Rotation

In Water (90)

$[\alpha]_D^{25} = -(88.50 + 0.145p)$; $= -(88.50 + 0.150\ C - 0.00086\ C^2)$, from $p = 2.6$ to 18.6 wt. % and from $C = 2.6$ to 20 g/100 ml. $[\alpha]_D^t = [\alpha]_D^{25} + (0.566 + 0.0028C)\ (t° - 25°)$; from 15 to 37°C. $[\alpha]_{589}^{20}/[\alpha]_{546}^{20} = 0.8467$. $[\alpha]_D^{20} = -(88.16 + 0.258p)$ (21). $[\alpha]_{546}^{25} = -105.30$; $[\alpha]_{589}^{25} = -89.40$ (78).

In Water, in Pyridine and in Formic Acid at 20°

Values of $-[\alpha]_\lambda^{20}$ for different concentrations (C) of levulose (30)

λ	In H_2O				In pyridine			
	$\frac{1}{2}N$	$\frac{1}{4}N$	$\frac{1}{16}N$	$\frac{1}{32}N$	$\frac{1}{2}N$	$\frac{1}{4}N$	$\frac{1}{16}N$	$\frac{1}{32}N$
656	76.39	75.30	74.86	74.04	26.44	25.81	25.39	24.77
589	90.46	89.96	88.36	87.49	35.48	35.26	34.96	34.51
535	107.21	106.66	105.70	104.84	42.59	42.22	41.71	41.24
508	136.85	135.8	133.35	130.12	49.10	48.77	48.36	47.62
479	151.11	149.27	147.20	146.20	56.0	55.37	54.78	54.07
447	166.55	163.88	160.49	158.10	63.93	62.70	62.11	61.33

Formic acid, C = 8.6 g/100 ml	λ	656	589	535	508	479	447
	$[\alpha]_\lambda^{20}$	37.25	46.77	52.83	64.66	75.54	85.84

Pyridine, C = 1.8 g/100 ml	°C	22	35	45
	$[\alpha]_{546}^t$	26.38	24.44	22.77

In Aqueous Ethyl Alcohol (2)

Composition: 2 moles levulose + 100 moles H_2O + x moles C_2H_5OH. Values of $[\alpha]_\lambda^{25}$

x \ λ	578 (HgY)	546 (HgG)	436 (HgB)
0	−93.73	−106.03	−175.29
9.28	−87.08	− 98.55	−162.65
24.65	−80.13	− 90.69	−149.62
54.9	−73.50	− 83.17	−137.48
167.0	−64.22	− 72.52	−120.59
1724.0	−49.7	− 55.7	− 93.7

In Various Solvents

Solvent	Levulose, g/100 ml	$[\alpha]_D^{20}$ α*	$[\alpha]_D^{20}$ $\alpha \rightleftarrows \beta$	$[\alpha]_D^{20}$ β	$10^3\ (k_1 + k_2)$	Lit.
Formamide	2.26		−109.51	−151.76	8.39	(60)
H_2O	10		− 92.0	−133.5		(44)
80% C_2H_5OH	10	−7	− 68.6	−133.5		(44)
95% C_2H_5OH		0	− 52.5	−122		(44)
CH_3OH		−8	− 61.4	−122		(44)

In Various Solvents.—(*Continued*)

Solvent		Levulose, g/100 ml	$[\alpha]_D^{20}$ α*	$[\alpha]_D^{20}$ $\alpha \leftrightarrows \beta$	$[\alpha]_D^{20}$ β	$10^3\ (k_1 + k_2)$	Lit.
80% C_2H_5OH						9.1†	(44)
H_2O		$\frac{1}{2}N$		− 90.5			(30)
Pyridine		$\frac{1}{2}N$		− 35.5			(30)
Formic acid		5 to 8		− 53.0			(30)
	t,°C			$[\alpha]_{546}^t$			
H_2O	14.3	9.942		−115.7	−161	65	(71)
H_2O	0.0	4.9		−123.6	−155	17	(71)
Aq., C_2H_5OH							
$d_4^{14} = 0.930$	15.3	10.06		− 96.4	−156	22	(71)
$d_4^{15} = 0.876$	0.0	4.9		− 96.1	−154	1	(71)

* Computed from solubilities and $[\alpha]_D$ for β-form. † $k_1 = 0.0047$.

Effect of HCl in H_2O (97)

% HCl	0	25	37.6	40.0	42.0
°C	9	8	8	8	8
$[\alpha]_D^t$	−95.1	−116	−133	−154	−180

Solubility

In H_2O (51)	°C	20	25	30	35	40	45	50	55
	% levulose	78.94	80.29	81.64	82.98	84.34	85.64	86.90	88.10

Solvent	g/100 ml solution Initial	g/100 ml solution Final	Composition, at equilibrium	Lit.
80% C_2H_5OH	13.4	27.4	48% β, 51% α	(44)
95% C_2H_5OH	1.8	4.2	43% β, 57% α	(44)
CH_3OH	5.2	11.1	47% β, 53% α	(44)

Mutarotation

With HCl at 30°C (37)

HCl, mole/l	0	0.0005	0.0010	0.0040	0.0100
$10^3\ (k_1 + k_2)$	186	140	128	130	196

Effect of pH and Temperature (68)

0.15°C		15°C		25°C		37°C	
pH	$10^3\ (k_1 + k_2)$	pH	$10^3\ (k_1 + k_2)$	pH	$10^3\ (k_1 + k_2)$	pH	$10^3\ (k_1 + k_2)$
1.33	101.0	2.5	64.7	2.5	118.9	1.70	460
2.48	16.2	3.3	36.8	3.4	86.0	2.06	350
3.17	8.5	5.1	41.5	5.1	99.2	3.36	195
5.07	8.7	5.8	53.5	5.7	107.6	4.62	205
6.00	10.4	6.3	64.7	6.4	156.1	5.10	236
6.28	17.8					6.10	275
						7.67	741

°C	0.15	15	25	37
$[\alpha]_D^t$ initial	−130.8	−130.8	−130.8	−130.8
$[\alpha]_D^t$ final	−100	− 94	− 88	− 81

Effect of Boric Acid (12)

Levulose, 1 molal, 0°C	H_3BO_3, m/l	0.22 molal	0.11 molal	0
	$10^3\ (k_1 + k_2)$	40	39	12.4

Velocity of Conversion of Artichoke Juices under Varying Conditions of Acidity and Temperature (51)

$$k = \frac{1}{t} \log_{10} \frac{R_0 - R_\infty}{R_t - R_\infty}$$

R_0, initial rotation; R_∞, rotation at completion of conversion

	t,°C	Acidity (apparent) normality	k
$R_0 = +0.08$, $R_\infty = -26.43$	79.8	0.10 H_2SO_4	0.0137
	79.8	.20 H_2SO_4	.0788
	78.2	.10 HCl	.0381
$R_0 = -2.40$, $R_\infty = -25.88$	99.0	0.0294 HCl	0.00327
	99.0	.0516 HCl	.02737
	99.0	.0667 HCl	.1371
$R_0 = -1.29$, $R_\infty = -34.48$	99.0	0.0240 HCl	0.0010
	99.0	.0462 HCl	.00593
	99.0	.0571 HCl	.0163
	99.0	.0676 HCl	.0353
	99.0	.0773 HCl	.0707
	99.0	.1041 HCl	.3172

The "apparent" acidities are those which would have been produced in pure water. A portion of the acid in each instance was rendered ineffective by inorganic impurities.

Velocity of Conversion of Inulin in the Presence of Varying Concentrations of Hydrochloric Acid at 100°C

Normality of HCl	Velocity constant, k	k (ash-free) in 0.01N HCl
0.0095	0.00641	$\frac{k(3-2)}{N(3-2)} = 0.0184$
0.0199	.0394	$\frac{k(4-3)}{N(4-3)} = 0.0212$
0.0545	.1022	$\frac{k(4-2)}{N(4-2)} = 0.0199$
0.1034	.2057	
Mean		0.020

By taking the differences in velocity at the higher acidities the neutralizing action of inorganic impurities is arithmetically eliminated.

Decomposition of Levulose in the Presence of Sulfuric Acid (51)

t,°C	Time in min	Acidity normality	Polarization in saccharimeter deg.
			86.25*
100	15	0.0304	83.70
100	30	.0304	82.90
100	15	.0584	83.30
100	30	.0584	81.16
			85.89*
70	15	.0474	85.87
70	30	.0474	85.63
70	15	.0891	85.79
70	30	.0891	85.26

* Control solution.

INVERT SUGAR

Mixture of equal parts of dextrose and levulose obtained by hydrolysis of sucrose.

Optical Rotation

In H_2O

$[\alpha]_D^{20} = -19.447 - 0.06068p + 0.000221p^2$ between $p = 9$ and 68 wt. %. All weights *in vacuo* (21). $[\alpha]_{546}^{25} = -21.50$. $[\alpha]_{589}^{25} = -18.39$ (78).

Effect of Various Substances on the Rotation

R (in°S) $= -42.00^0 - 10^{-3}\,am$, where m = g anhyd. reagent per 100 ml of solution and R is twice the rotation (in°S) observed with 13 g of inverted sucrose per 100 ml. Ac = $C_2H_3O_2$ (48).

Reagent	HCl	NaCl	NH_4Cl	$CaCl_2$	$K_2C_2O_4$	HAc	H_3PO_4
a	540.7	540	563	710	510	82.3	77.6
For m ≯	9.3	3.7	3.7	7.5	12.9	41	5.5

Reagent	xPbAc$_2 \cdot y$PbO	PbAc	NH_4NO_3	KCl	Na_2HPO_4·12 aq.	NaAc. 3 aq.
a	−1430	20	399	486	161	189
At m =	2.57	3.03	2.68	11.8	12.26	12.85

Decomposition in the Presence of HCl, 0.7925N (48)

50°C	Min	0	38	78	128	235
	°S	33.25	33.04	32.95	32.80	32.44

60°C	Min	0	8	18	33	48	63	93
	°S	33.25	33.11	32.93	32.76	32.60	32.31	32.02

70°C	Min	0	4	8	12	17	22	32
	°S	33.25	33.00	32.62	32.46	32.26	31.89	31.45

80°C	Min	0	3	6	10	14	19
	°S	33.25	32.61	32.00	31.30	30.82	30.07

$C_6H_{12}O_6$, MANNOSE

Optical Rotation

In H_2O

C = g anhyd. mannose per 100 cm³ solution at 20°C (44)

C	3.25	4.53	10.2	16.9	20.5_5
$[\alpha]_D^{20}$	14.6	14.5	14.1	13.6	13.4

C	30.1_5	39.7	50	60	70	80
$[\alpha]_D^{20}$	13.1	12.8	12.3	11.9	11.4	10.9

In Various Solvents

Solvent	Mannose, g/100 ml	°C	$[\alpha]_D^t$ α	$[\alpha]_D^t$ $\alpha \rightleftarrows \beta$	$[\alpha]_D^t$ β	Lit.
H_2O	2.8	19		+14.40	−19.9	(61)
Formamide	2.0	20		11.84	−26.9	(61)
H_2O		20	+34*	14.6	−17.	(44)
80% C_2H_5OH		20	+34*	25.7	−14.9	(44)
CH_3OH		20	39*	30.1	−16.5	(44)
H_2O		20	30			(56)
80% C_2H_5OH		20	35			(56)

* Computed from initial and final solubilities and rotations of the β-form.

Effect of HCl on d-mannose

Ca. 5 g anhyd. mannose per 100 ml solution (97)

% HCl	0	8	25	31	37.6	40.0	42.0
°C	13	10	10	10	10	10	10
$[\alpha]_D^t$	+14.1	+10.5	+4.0	+3.0	+13.3	+31.3	+54.6

Effect of H_2SO_4

1.25 g anhyd. mannose in 25 cm³; H_2SO_4 = 24N; 25°C (11)

t, min	5	10	20	30	60	120	240	360
α, °arc	−8.3	−8.3	−7.5	−6.7	−5.0	−1.8	±0.0	+2.5

Solubility

Solid phase: β-mannose; 20°C; g/100 cm³ solution ([44])

Solvent	Initial	Final	$\alpha \rightleftarrows \beta$ mix.	
			%α	%β
100% CH_3OH	0.78	4.4		
80% C_2H_5OH	2.4	13.0	82	18

Mutarotation

In H_2O

C = g mannose per 100 cm³ of solution; 19.7°C ([43])

C	5.13	8.0	10.0	10.2	19.1	24.7
$10^3\ (k_1 + k_2)$	17.7	17.9	17.5	17.8	18.1	19.1
C	27.1	36.8	45.0	50.0	52.0	56.0
$10^3\ (k_1 + k_2)$	19.2	19.7	20.0	19.2	18.9	17.9

In Dilute ($\not>$10%) Solution ([43])

Between 0 and 45°C, $k_1 + k_2$ may be computed with an accuracy of *ca.* 5% by means of the equation: $\log_{10} 10^3\ (k_1 + k_2) = 13.132 - 3472/T$ where T is the absolute temperature.

Effect of HCl at 19.7°C ([43])

HCl, N	0	0.001	0.010	0.0125	0.0166	0.025	0.05	0.10
$10^3\ (k_1 + k_2)$	17.7	19.0	39.6	46.0	55.8	70.8	125	238

In Various Solvents

Solvent	°C	$10^3(k_1 + k_2)$		10^3k_1	10^3k_2	Lit.
		α	β			
H_2O	1.5	2.9	2.9			([57])
80% C_2H_5OH	25	5.4	5.75			([57])
80% C_2H_5OH	15.0			0.41	1.93	([57])
80% C_2H_5OH	20.0		3.63	.77	2.86	([44])
H_2O	18.0		17.			([11])
H_2O	19.0		27.3			([61])
Formamide	20.0		3.26			([61])

$C_6H_{12}O_6$, GALACTOSE

Optical Rotation

In Various Solvents

Solvent	Galactose, g/100 ml	°C	$[\alpha]_D^t$			$10^3\ (k_1 + k_2)$	Lit.
			α	$\alpha \rightleftarrows \beta$	β		
H_2O	2.18	12.5	+139.3	+79.3		4.79	([60])
Formamide	2.01	18.0	154.5	85.45		0.84	([60])
H_2O	2.25	20.0	139.4	79.25		9.60	([61])
Formamide	1.75	20.0	155.3	87.77		1.98	([61])
H_2O	1.87	20.0		79.01	+56.51	7.22	([61])
Formamide	1.81	20.0		87.19	62.30	1.57	([61])
H_2O			144.0	80.05	47.0*		([44])
60% C_2H_5OH		20.0	140.6	72.8	33*		([44])
80% C_2H_5OH		20.0	127.2	73.1	34*		([44])
H_2O		20.0			52		([44])
H_2O	1.0	20.0		80.2			([30])

* Calculated from initial and final solubilities and rotations.

$$\frac{d[\alpha]_D^t}{dt} = -0.23 \text{ at } 12.5°C = -0.34 \text{ at } 18°C\ (^{60}).$$

Effect of HCl in H_2O ([97])

% HCl	0	25	37.6	40.0	42.0
°C	8	6	6	6	6
$[\alpha]_D^t$	83.3	94.2	113.8	133.6	160.4

Effect of H_2SO_4 in H_2O ([11])

N of H_2SO_4	0	10	16	18	20	24	26
$[\alpha]_D^{25}$	79.0	88.0	95.0	99.5	102.5	110.0	122.0

Equilibrium Rotation

In Aqueous C_2H_5OH ([13])

% C_2H_5OH	$[\alpha]_D^{20}$	$[\alpha]_D^{30}$	$[\alpha]_D^{38}$
30	71.2	66.4	63.3
60	63.3	60.5	57.4
80	57.0	51.0	41.6

In Aqueous n-Propyl Alcohol ([13, 26])

C_3H_7OH, g/l solution	100	200	300	400	500	600
$[\alpha]_D^{20}$	79.66	76.13	74.04	71.56	68.97	64.96

In Various Solvents

Values of $[\alpha]_\lambda^{20}$ ([30])

Galactose, g/100 ml	1	1	2.98
λ, mμ	In H_2O	Pyridine	Formic acid
656	60.50	46.50	101.42
589	80.17	59.83	127.30
535	96.66	76.66	155.30
508	117.50	85.33	175.80
479	131.00	98.66	221.10
447	150.66	115.33	250.80

Index of Refraction and Density of Aqueous Solution ([77])

% anhydrous galactose	18.24	9.12	4.60	2.30	1.15
d_4^{25}	1.0730	1.0335	1.0150	1.0058	1.0012
n_D^{25}	1.3620	1.3470	1.3400	1.3366	1.3349

Solubility

g α-galactose per 100 cm³ solution

Solvent	Initial	Final	Lit.
80% C_2H_5OH	0.27	0.65	([38])
60% C_2H_5OH	1.1	3.1	([38])

Mutarotation ([12])

Solvent	Galactose, g/100 ml	°C	$10^3(k_1 + k_2)$
Conductivity H_2O	9.0	25.0	1.41
0.5N H_3BO_3	9.0	25.0	1.45

$C_5H_{10}O_5$, ARABINOSE

Optical Rotation and Mutarotation

In Various Solvents

Solvent	Arabinose, g/100 ml	°C	$[\alpha]_D^t$			$10^3\ (k_1 + k_2)$	Lit.
			α	$\alpha \rightleftarrows \beta$	β		
H_2O	2.61	12		+105.9(l-)	+186(l-)	13.4	([60])
H_2O		20	−54*(d-)	−105.0(d-)	−175(d-)	31	([44])
80% C_2H_5OH		20	−28*(d-)	− 81.7(d-)	−173(d-)		([44])
Formamide	2.40	13		+116.3(l-)	+189(l-)	1.54	([60])

* Calculated from initial and final solubilities and rotations.

Effect of HCl in Aqueous Solution

Arabinose, *ca.* 5 g/100 ml ([97])

% HCl	0	25	37.6	40	42
°C	9	8	8	8	8
$[\alpha]_D^t$	+105.1	117.6	142.0	166.2	202.9

40% HCl					
t, min	6	18	48	64
$[\alpha]_D^{10}$	+166.3	167.0	167.0	167.0

Solubility ([44])

In 80% aqueous C_2H_5OH: Initial $S_\beta = 0.74$, final $S_\beta = 1.94$ g per 100 cm³ solution. Equilibrium mixture = 38% β, 62% α.

$C_5H_{10}O_5$, XYLOSE

Optical Rotation and Mutarotation

In Various Solvents

Solvent	Xylose, g/100 ml	°C	$[\alpha]_D^t$ α	$[\alpha]_D^t$ $\alpha \rightleftarrows \beta$	$[\alpha]_D^t$ β	$10^3 (k_1 + k_2)$	Lit.
H_2O........		20	+ 92.0	+19.0	−20*		(44)
80% C_2H_5OH		20	+ 94.5	+32.1	−20*		(44)
H_2O........		1				2.8	(44)
H_2O........		10				7.5	(44)
H_2O........		20				20.7	(44)
H_2O........		30				53.2	(44)
H_2O........		40				133	(44)
H_2O........	2.72	20	+ 90.3	+19.13		18.8	(60)
Formamide..	4.04	20	+109.4	+25.12		3.06	(60)
H_2O........		20		+18.2			(30)
Pyridine....		20		+40.5			(30)
Formic acid.		20		+66.6			(30)

* Calculated from initial and final solubilities and rotations of the α-form.

Effect of HCl in Aqueous Solution (*ca.* 5 g/100 ml) (97)

% HCl............	0	8	25	37.6	40.0	42.0
°C................	13	9	9	9	9	9
$[\alpha]_D^t$	+17.6	21.3	27.4	46.4	68.7	96.6

Rotation at Equilibrium (30)

Values of $[\alpha]_\lambda^{20}$ for $\alpha \rightleftarrows \beta$

Xylose, g/100 ml / λ, mμ	0.866 In H_2O	1.28 Pyridine	5.48 Formic acid
656	+13.28	32.04	55.74
589	18.19	40.64	66.60
535	21.08	48.64	82.66
508	24.50	59.90	95.80
479	27.70	68.34	116.13
447	31.94	72.47	125.95

Solubility

In 80% C_2H_5OH at 20°C: Initial 2.7 g, final 6.2 g per 100 cm³ solution. Equilibrium mixture, 44% α, 56% β (44).

$C_{18}H_{32}O_{16} + 5H_2O$, RAFFINOSE (MELITRIOSE, GOSSYPOSE)

(Composition: *d*-Galactose < *d*-Glucose < > *d*-Fructose)

Raffinose may be hydrolyzed to (1) fructose and melibiose; (2) galactose and sucrose; (3) fructose, glucose, and galactose. It is nonreducing.

Optical Rotation

In H_2O

Form		Lit.
$R \cdot 5H_2O$............	$[\alpha]_D^{20} = 104.5$	(16, 54)
Anhyd..............	$[\alpha]_{589.25}^{25} = 123.00$	(62, 91, 93)
Anhyd..............	$[\alpha]_{546.1}^{25} = 144.55$	(94)

$\frac{d[\alpha]_\lambda}{dt}$ = *ca.* 0.0 between 3° and 20°C (23).

In Various Solvents (30)

C = 3.7125 g anhyd. raffinose per 100 ml solution. Values of $[\alpha]_\lambda^{20}$

λ, mμ =	656	589	535	508	479	447
In H_2O.....	79.63	105.20	131.71	150.75	163.77	188.55
Pyridine....	94.22	117.17	142.76	167.00	188.52	218.26

Effect of Salts in H_2O (91, 92, 93, 94)

0.1 formula weight $C_{18}H_{32}O_{16}$ in 1000 g H_2O

Salt	Moles/1000 g H_2O	$[\alpha]_{589.25}^{25}$
	0.0	123.00
KCl................	1.3	123.08
NaCl................	1.71	123.12

Effect of Salts in H_2O (91, 92, 93, 94).—(*Continued*)

Salt	Moles/1000 g H_2O	$[\alpha]_{589.25}^{25}$
LiCl................	1.30	123.24
		$[\alpha]_{546.1}^{24}$
	0.0	144.55
CsCl................	1.2	144.64

Density of Aqueous Solution

d_{20}^{20} of aqueous solution containing 28.4% raffinose = 1.12474. Since this corresponds to 29.10° sucrose Brix, 1% raffinose = 1.025° sucrose Brix (80).

C = formula weights of raffinose·$5H_2O$ per liter of solution at t°C, all weights *in vacuo* (95).

C	°C	d_t^t	C	°C	d_t^t
0.038083	0.00	1.00796	0.102297	24.94	1.01179
.037973	24.94	1.00483	.131202	0.00	1.02752
.037615	49.87	.99556	.130727	24.96	1.02378
.058632	0.00	1.01218	.129787	50.12	1.01407
.058466	24.94	1.00897	.176625	0.00	1.03645
.057925	49.87	.99964	.175818	24.00	1.03172
.102676	0.00	1.02147	.174336	49.84	1.02302

Solubility

In H_2O. Per Cent Anhyd. Raffinose

°C..............	0	10	16	24
%..............	6.5	10.0	14.5	28.4
Lit..............	(15)	(15)	(15)	(80)

In Aqueous CH_3OH at 15°C

S in g anhyd. raffinose per 100 cm³ solution (31)

Vol. % CH_3OH...........	100	95	90	85	80	60	20
S........................	10.2	7.5	2.4	1.8	1.8	2.8	5.0

Hydrolysis of Raffinose by Acids at 25°C (1)

100 g H_2O + 0.25 mole of anhyd. raffinose + 1 mole of acid

Acid	HNO_3	HCl	H_2SO_4
$k = \frac{1}{t} \log_{10} \frac{a}{a-x}$	0.00390	0.00419	0.00446

SYSTEMS CONTAINING MORE THAN ONE SUGAR

Solubilities

System: Sucrose, Dextrose, Water, 30°C (50)

Solid phase	% sucrose	% dextrose	d_4^{30}
$C_{12}H_{22}O_{11}$......................	68.11	0	1.3301
	64.22	4.89	1.3356
	60.40	9.70	1.3411
	53.19	18.58	1.3507
	48.60	24.61	1.3588
$C_{12}H_{22}O_{11} + C_6H_{12}O_6.H_2O$........	47.10	26.59	
$C_6H_{12}O_6.H_2O$..................	33.79	33.88	1.3227
	19.66	41.97	1.2867
	7.35	50.00	1.2592
	0	54.64	1.2434

Solubility of Sucrose, Dextrose, and Levulose in the Presence of One Another

Solid phase sucrose (50)

23.15°C	% invert sugar.....	0	11.90	25.39	36.90
	% sucrose.........	67.59	57.84	47.31	38.66

At 30°C

% invert sugar	% sucrose	d_4^{30}	% invert sugar	% sucrose	% invert sugar	% sucrose
0	68.11	1.3301	24.52	48.93	47.62*	31.85
14.94	56.32	1.3485	28.01	46.36	56.37	26.03
21.86	50.97	1.3571	37.48	39.23	63.68	21.18
23.21	49.91	1.3587	47.02*	32.06	64.47	20.59
24.46	48.95	1.3608				

* d_4^{30} = 1.3957.

At 50°C

% invert sugar	0	11.42	22.65	32.32	46.05	57.06
% sucrose....	72.25	62.81	53.80	46.20	35.75	28.18

Both sugars present as solid phases ([50])

°C................	0	10	15	23.15	30	40	50
% sucrose..........	43.7	40.9	39.1	36.3	33.6	31.1	27.7
% invert sugar......	27.2	31.8	34.8	39.9	45.4	50.7	58.0

System: Dextrose, Levulose, Water, 30°C

Solid phase dextrose monohydrate ([50])

% anhyd. dextrose	% levulose	d_4^{30}	% anhyd. dextrose	% levulose	d_4^{30}
54.64	0.00		35.76	33.09	1.3286
49.34	8.94	1.2639	34.48	35.69	1.3359
49.32	8.94	1.2650	33.67	37.10	1.3408
45.97	14.50	1.2779	32.55	39.39	1.3480
41.01	23.23	1.3000			

System: Dextrose, Levulose, Water

Solid phase, dextrose. A = % dextrose, in water alone. B = % dextrose in solution containing an equivalent amount of levulose. Saturation with crystalline dextrose in both cases ([50]).

°C	A	B	°C	A	B
0	35.0	50.8	30.0	54.64	69.7
10.0	40.8	56.6	35.0	58.02	72.2
15.0	44.0	59.8	40.0	61.87	74.8
20.0	47.2	62.6	45.0	65.71	78.0
25.0	50.80	66.2	50.0	70.91	81.9

Clerget Analysis for Sucrose ([48])

The estimation of sucrose in the presence of other optically active substances by the Clerget Method depends upon the change of rotation which the sugar undergoes upon inversion. The difference in saccharimeter deg. between the rotation of 26 g of pure sucrose in 100 ml of solution observed in a 200 mm column and the rotation of invert sugar calculated to a concentration of 26 g of inverted sucrose in 100 ml is known as the Clerget Divisor. Two general methods of inversion are employed:

(a) Inversion by the enzyme, invertase.[1]

(b) Inversion by hydrochloric acid.[2]

Values of Clerget Divisor

(m_s, resp. m_A, resp. m_N, resp. m_{Na} = g inverted sucrose, resp. HCl, resp. NH_4Cl, resp. NaCl in 100 ml of solution. t = °C.)

(a) Invertase inversion.

Positive constituent	Negative constituent
+100	$-42.1 - 0.0676\,(m_s - 13) + t/2$

(b) HCl inversion, 2.312 g anhyd. HCl in 100 ml of inverted solution, equivalent to 10 ml of HCl (d_4^{20} = 1.1029).

Positive constituent	Negative constituent
+100	$-43.25 - 0.0676\,(m_s - 13) + t/2$

(c) HCl inversion and subsequent neutralization with NH_4OH equivalent to 10 ml HCl (d_4^{20} = 1.1029) in 100 ml of inverted solution.

Positive constituent	Negative constituent
+100	$-43.91 - 0.0676\,(m_s - 13) + t/2$

(d) HCl inversion with 10 ml of HCl (d_4^{20} = 1.1029) in 100 ml of inverted solution; 2.315 g NaCl contained in 100 ml of solution for direct polarization (in order to equalize the effect of HCl upon invert sugar when present as an impurity).

Positive constituent	Negative constituent
+99.38	$-42.1 - 0.0676\,(m_s - 13) + t/2$

(e) HCl inversion with 10 ml HCl (d_4^{20} = 1.1029) in 100 ml of inverted solution and subsequent neutralization with NH_4OH; 3.392 g NH_4Cl contained in 100 ml of solution for direct polarization.

Positive constituent	Negative constituent
+99.43	$-43.91 - 0.0676\,(m_s - 13) + t/2$

Generalized Formulae

Positive constituent: $R = 100 - 0.265\,m_{Na} = 100 - 0.169\,m_N$.

Negative constituent: $R_{HCl} = -41.12 - 0.5407 m_A - 0.0676\, m_s + 0.5\, t$. $R_{NH_4Cl} = -41.12 - 0.563 m_N - 0.0676 m_s + 0.5 t$.

Reducing Powers toward Fehling's Solution

For Munson and Walker's table for calculating dextrose, invert sugar, in mixtures containing sucrose, lactose and maltose *v.* ([18], [65]). For Allihn's tables *v.* ([14], [20]).

[1] For detailed description of methods of inversion by invertase, *v.* ([3]).

[2] For detailed description of methods of inversion by hydrochloric acid, *v.* ([48]).

ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES ([40-5])

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
β-*d*-Arabinose..................	$C_5H_{10}O_5$	150		−175	− 26 300	H_2O
α-*l*-Arabinose tetraacetate..................	$C_{13}H_{18}O_9$	318	97	+ 42.5	+ 13 500	$CHCl_3$
β-*l*-Arabinose tetraacetate..................	$C_{13}H_{18}O_9$	318	86	+147.2	+ 46 800	$CHCl_3$
l-Arabonic amide..................	$C_5H_{11}O_5N$	165	136	+ 37.5	+ 6 190	H_2O
d-Arabonic phenylhydrazide..................	$C_{11}H_{16}O_5N_2$	256		− 14.5	− 3 710	H_2O
β-Bromoacetyl *d*-arabinose..................	$C_{11}H_{15}O_7Br$	339		−288	− 97 600	$CHCl_3$
β-Bromoacetyl *l*-arabinose..................	$C_{11}H_{15}O_7Br$	339		+288	+ 97 600	$CHCl_3$
α-Bromoacetyl lactose..................	$C_{26}H_{35}O_{17}Br$	699	145	+109	+ 76 200	$CHCl_3$
α-Bromoacetyl *d*-xylose..................	$C_{11}H_{15}O_7Br$	339	102	+212	+ 71 900	$CHCl_3$
β-Cellobiose..................	$C_{12}H_{22}O_{11}$	342		+ 16.0	+ 5 470	H_2O
α-Cellobiose octaacetate..................	$C_{28}H_{38}O_{19}$	678	229	+ 41	+ 27 800	$CHCl_3$
β-Cellobiose octaacetate..................	$C_{28}H_{38}O_{19}$	678	202	− 14.6	− 9 900	$CHCl_3$
α-Chondrosamine pentaacetate..................	$C_{16}H_{23}O_{10}N$	389	183	+101.3	+ 39 400	$CHCl_3$
β-Chondrosamine pentaacetate..................	$C_{16}H_{23}O_{10}N$	389	220 d	+ 10.5	+ 4 080	$CHCl_3$
β-Chloroacetyl *d*-arabinose..................	$C_{11}H_{15}O_7Cl$	295		−244	− 72 000	$CHCl_3$

ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5).—(*Continued*)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
β-Chloroacetyl *l*-arabinose	$C_{11}H_{15}O_7Cl$	295		+244	+ 72 000	$CHCl_3$
Chloroacetyl celtrobiose (40)	$C_{26}H_{35}O_{17}Cl$	655	138	+ 59.2	+ 38 800	$CHCl_3$
Chloroacetyl *d*-galactose (second)	$C_{14}H_{19}O_9Cl$	367	67	− 78	− 28 600	$CHCl_3$
α-Chloroacetyl lactose	$C_{26}H_{35}O_{17}Cl$	655	121	+ 84	+ 55 000	$CHCl_3$
α-Chloroacetyl neolactose (53)	$C_{26}H_{35}O_{17}Cl$	655	182	+ 71.2	+ 46 700	$CHCl_3$
β-*d*-Fructose	$C_6H_{12}O_6$	180		−133.5	− 24 000	H_2O
α-*d*-Fructose pentaacetate	$C_{16}H_{22}O_{11}$	390	70	+ 34.7	+ 13 500	$CHCl_3$
β-*d*-Fructose pentaacetate	$C_{16}H_{22}O_{11}$	390		−120.9	− 47 200	$CHCl_3$
β-*d*-Fructose tetraacetate	$C_{14}H_{20}O_{10}$	348		− 91.6	− 31 900	$CHCl_3$
d-Galactonic amide	$C_6H_{13}O_6N$	195	172	+ 30.2	+ 5 890	H_2O
α-*d*-Galactose	$C_6H_{12}O_6$	180		+144	+ 25 900	H_2O
β-*d*-Galactose	$C_6H_{12}O_6$	180		+ 52	+ 9 360	H_2O
d-Galactose pentaacetate (first)	$C_{16}H_{22}O_{11}$	390	142	+ 23	+ 8 970	$CHCl_3$
d-Galactose pentaacetate (second)	$C_{16}H_{22}O_{11}$	390	96	+107	+ 41 700	$CHCl_3$
d-Galactose pentaacetate (third)	$C_{16}H_{22}O_{11}$	390	98	− 42	− 16 400	$CHCl_3$
d-Galactose pentaacetate (fourth)	$C_{16}H_{22}O_{11}$	390	87	+ 61	+ 23 800	$CHCl_3$
d-Galactose tetraacetate (third)	$C_{14}H_{20}O_{10}$	348	73	− 17.8	− 6 190	$CHCl_3$
d-Galactose phenylhydrazone	$C_{20}H_{26}O_9N_2$	438	95	+ 15.5	+ 6 790	$CHCl_3$
d-α-Galaheptonic amide	$C_7H_{15}O_7N$	225	206	+ 14.3	+ 3 220	H_2O
d-α-Galaheptonic phenylhydrazide	$C_{13}H_{20}O_7N_2$	316		+ 8.5*	+ 2 700*	H_2O
α-Gentiobiose octaacetate	$C_{28}H_{38}O_{19}$	678	189	+ 52.4	+ 35 500	$CHCl_3$
β-Gentiobiose octaacetate	$C_{28}H_{38}O_{19}$	678	193	− 5.3	− 3 590	$CHCl_3$
d-α-Glucoheptonic amide	$C_7H_{15}O_7N$	225	134	+ 10.6	+ 2 390	H_2O
d-β-Glucoheptonic amide	$C_7H_{15}O_7N$	225	158	− 30.2	− 6 790	H_2O
d-α-Glucoheptonic phenylhydrazide	$C_{13}H_{20}O_7N_2$	316		+ 9.3	+ 2 940	H_2O
β-*d*-α-Glucoheptose	$C_7H_{14}O_7$	210		− 28.4	− 5 960	H_2O
α-*d*-α-Glucoheptose hexaacetate	$C_{19}H_{26}O_{13}$	462	164	+ 87.0	+ 40 200	$CHCl_3$
β-*d*-α-Glucoheptose hexaacetate	$C_{19}H_{26}O_{13}$	462	135	+ 4.8	+ 2 220	$CHCl_3$
d-Gluconic amide	$C_6H_{13}O_6N$	195	144	+ 31.2	+ 6 080	H_2O
α-*d*-Glucosamine pentaacetate	$C_{16}H_{23}O_{10}N$	389	140	+ 93.5	+ 36 400	$CHCl_3$
β-*d*-Glucosamine pentaacetate	$C_{16}H_{23}O_{10}N$	389	189	+ 1.2	+ 467	$CHCl_3$
α-*d*-Glucose	$C_6H_{12}O_6$	180		+113	+ 20 300	H_2O
β-*d*-Glucose	$C_6H_{12}O_6$	180		+ 19	+ 3 420	H_2O
α-*d*-Glucose pentaacetate	$C_{16}H_{22}O_{11}$	390	113	+101.6	+ 39 600	$CHCl_3$
β-*d*-Glucose pentaacetate	$C_{16}H_{22}O_{11}$	390	132	+ 3.8	+ 1 480	$CHCl_3$
d-Gulonic amide	$C_6H_{13}O_6N$	195	123	+ 15.2	+ 2 960	H_2O
α-Iodoacetyl lactose	$C_{26}H_{35}O_{17}I$	746	145	+137	+102 000	$CHCl_3$
α-Lactose	$C_{12}H_{22}O_{11}$	342		+ 90	+ 30 800	H_2O
β-Lactose	$C_{12}H_{22}O_{11}$	342		+ 35	+ 12 000	H_2O
α-Lactose octaacetate	$C_{28}H_{38}O_{19}$	678	152	+ 53.9	+ 36 500	$CHCl_3$
β-Lactose octaacetate	$C_{28}H_{38}O_{19}$	678	90	− 4.3	− 2 920	$CHCl_3$
α-*d*-Lyxose	$C_5H_{10}O_5$	150		+ 5.5	+ 825	H_2O
β-Maltose	$C_6H_{12}O_6$	342		+118	+ 40 400	H_2O
β-Maltose heptaacetate	$C_{26}H_{36}O_{18}$	636	181	+ 67.8	+ 43 100	$CHCl_3$
α-Maltose octaacetate	$C_{28}H_{38}O_{19}$	678	125	+122.4	+ 83 000	$CHCl_3$
β-Maltose octaacetate	$C_{28}H_{38}O_{19}$	678	160	+ 62.7	+ 42 500	$CHCl_3$
d-Mannitol hexaacetate	$C_{18}H_{26}O_{12}$	434	120	+ 26	+ 11 300	$CHCl_3$
d-α-Mannoheptonic amide	$C_7H_{15}O_7N$	225	194	+ 28	+ 6 300	H_2O
d-α-Mannoheptonic phenylhydrazide	$C_{13}H_{20}O_7N$	316		+ 21	+ 6 640	H_2O
d-α-Mannoheptose hexaacetate (first)	$C_{19}H_{26}O_{13}$	462	106	+ 24.2	+ 11 200	$CHCl_3$
d-α-Mannoheptose hexaacetate (second)	$C_{19}H_{26}O_{13}$	462	140	− 31	− 14 300	$CHCl_3$
d-Mannonic amide	$C_6H_{13}O_6N$	195	173	− 17.3	− 3 370	H_2O
d-Mannonic phenylhydrazide	$C_{12}H_{18}O_6N_2$	286		− 8.1*	− 2 320*	H_2O
d-Mannosaccharic diamide	$C_6H_{12}O_6N_2$	208	189	− 24.5	− 5 100	H_2O
β-*d*-Mannose	$C_6H_{12}O_6$	180		− 17	− 3 060	H_2O
α-*d*-Mannose pentaacetate	$C_{16}H_{22}O_{11}$	390	64	+ 55.0	− 21 500	$CHCl_3$
β-*d*-Mannose pentaacetate	$C_{16}H_{22}O_{11}$	390	118	− 25.2	− 9 830	$CHCl_3$
Melezitose	$C_{18}H_{32}O_{16}$	504	148	+ 88.2	+ 44 500	H_2O
Melezitose hendekaacetate	$C_{40}H_{54}O_{27}$	966	117	+103.8	+100 000	$CHCl_3$
β-Melibiose	$C_{12}H_{22}O_{11}$	342		+ 12.4	+ 42 400	H_2O
β-Melibiose octaacetate	$C_{28}H_{38}O_{19}$	678	177	+102.5	+ 69 500	$CHCl_3$

ROTATION AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5)—(Continued)

	Formula	Mol. wt.	M. P.	$[\alpha]^{20}_{D}$	$[M]^{20}_{D}$	Solvent
α-Methyl *l*-arabinoside	$C_6H_{12}O_5$	164	131	+ 17.3	+ 2 840	H_2O
β-Methyl *l*-arabinoside	$C_6H_{12}O_5$	164	169	+245.5	+ 40 300	H_2O
β-Methyl *l*-arabinoside triacetate	$C_{12}H_{18}O_8$	290	85	+182.0†	+ 52 800†	$CHCl_3$
β-Methyl cellobioside heptaacetate	$C_{27}H_{38}O_{18}$	650	187	− 25.4	− 16 500	$CHCl_3$
β-Methyl *d*-fructoside	$C_7H_{14}O_6$	194	120	−172.1	− 33 400	H_2O
β-Methyl *d*-fructoside tetraacetate	$C_{15}H_{22}O_{10}$	362	76	−124.6	− 45 100	$CHCl_3$
α-Methyl *d*-galactoside tetraacetate	$C_{15}H_{22}O_{10}$	362		+133.0	+ 48 100	$CHCl_3$
β-Methyl *d*-galactoside tetraacetate	$C_{15}H_{22}O_{10}$	362		− 13.0	− 4 710	$CHCl_3$
β-Methyl gentiobioside	$C_{13}H_{24}O_{11}$	356	98	− 36.0	− 12 800	H_2O
β-Methyl gentiobioside heptaacetate	$C_{27}H_{38}O_{18}$	650	82	− 18.9	− 12 300	$CHCl_3$
α-Methyl *d*-glucoside tetraacetate	$C_{15}H_{22}O_{10}$	362	101	+130.6	+ 47 300	$CHCl_3$
β-Methyl *d*-glucoside tetraacetate	$C_{15}H_{22}O_{10}$	362	105	− 18.3	− 6 620	$CHCl_3$
α-Methyl *d*-lyxoside (73)	$C_6H_{12}O_5$	164	109	+ 59.4		H_2O
β-Methyl maltoside heptaacetate	$C_{27}H_{38}O_{18}$	650	125	+ 53.7	+ 34 900	$CHCl_3$
α-Methyl *d*-xyloside	$C_6H_{12}O_5$	164		+153.9	+ 25 200	H_2O
β-Methyl *d*-xyloside	$C_6H_{12}O_5$	164	157	− 65.5	− 10 700	H_2O
α-Methyl *d*-xyloside triacetate	$C_{12}H_{18}O_8$	290	86	+119.6	+ 34 700	$CHCl_3$
β-Methyl *d*-xyloside triacetate	$C_{12}H_{18}O_8$	290	115	− 60.7	− 17 600	$CHCl_3$
α-Neolactose octaacetate (53)	$C_{28}H_{38}O_{19}$	678	178	+ 53.4	+ 36 200	$CHCl_3$
β-Neolactose octaacetate (53)	$C_{28}H_{38}O_{19}$	678	148	− 7.1	− 4 810	$CHCl_3$
l-Rhamnomethyltetronic amide	$C_5H_{11}O_4N$	149	135	+ 54.8	+ 8 170	H_2O
l-Rhamnomethyltetronic lactone	$C_5H_8O_4$	132	123	− 44.7	− 5 900	H_2O
l-Rhamnonic phenylhydrazide	$C_{12}H_{18}O_5N_2$	270		+ 17.2	+ 4 640	H_2O
α-*l*-Rhamnose	$C_6H_{12}O_5$	164		− 7.7	− 1 260	H_2O
l-Ribonic amide	$C_5H_{11}O_5N$	165	138	− 16.4	− 2 710	H_2O
d-Saccharic diamide	$C_6H_{12}O_6N_2$	208	173	+ 13.3	+ 2 770	H_2O
Sedoheptose (anhydro-)	$C_7H_{12}O_6$	210		−146.3	− 30 720	H_2O
Sucrose octaacetate	$C_{28}H_{38}O_{19}$	678	69	+ 59.6	+ 40 400	$CHCl_3$
Trehalose octaacetate	$C_{28}H_{38}O_{19}$	678	98	+162.3	+110 000	$CHCl_3$
α-*d*-Xylose	$C_5H_{10}O_5$	150		+ 92	+ 13 800	H_2O
α-*d*-Xylose tetraacetate	$C_{13}H_{18}O_9$	318	59	+ 89.1	+ 28 300	$CHCl_3$
β-*d*-Xylose tetraacetate	$C_{13}H_{18}O_9$	318	128	− 24.9	− 7 920	$CHCl_3$
d-Xylose triacetate	$C_{11}H_{16}O_8$	276	141	+ 70†	+ 19 300†	$CHCl_3$

* At 80°C. † At 23°C.

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(70) Nutting, *2*, **17**: 1; 03. (71) Patterson, *4*, **109**: 1204; 16. (72) Pennycuick, *4*, **125**: 2049; 24. (73) Phelps and Hudson, *1*, **48**: 503; 26. (74) Pionchon, *34*, **124**: 1523; 97. (75) Plato, *Kaiserlichen Normal-Eichungs-Kommission, Wiss. Abh.*, **2**: 153; 00. (76) Prinsen-Geerligs, *275*, **10**: 68; 08. (77) Pulvermacher, *93*, **113**: 141; 20. (78) Quisumbing and Thomas, *1*, **43**: 1503; 21. (79) Saillard, *378*, **2**: 1035; 19.

(80) Schecker, *445*, **74**: 82; 24. (81) Schliephacke, *13*, **377**: 164; 10. (82) Schönrock, *445*, **54 II**: 521; 04. (83) Schönrock, *445*, **61 II**: 421; 11. (84) Schönrock, *243*, **43**: 69; 23. (85) Smits and Gillis, *64P*, **20**: 520; 18. (86) Staněk, *446*, **35**: 57; 10. (87) Staněk, *446*, **45**: 417; 21. (88) Tollens, *25*, **10**: 1403; 77. (89) Tollens, *25*, **17**: 2234; 84.

(90) Vosburgh, *1*, **42**: 1696; 20. (91) Washburn, *1*, **31**: 322; 09. (92) Washburn, *7*, **66**: 513; 09. (93) Washburn, *445*, **60 II**: 381; 10. (94) Washburn and Millard, *1*, **37**: 694; 15. (95) Washburn and Williams, *1*, **35**: 750; 13. (96) Wilcox, *50*, **5**: 587; 01. (97) Zechmeister, *7*, **103**: 316; 22.

X-RAY DIFFRACTION DATA—MISCELLANEOUS NATURAL AND INDUSTRIAL MATERIALS

RALPH W. G. WYCKOFF

The following bibliography contains references to qualitative and quantitative studies by means of X-rays on various natural and industrial materials, and supplements the quantitative data on pure metals, alloys, soaps, etc., presented in vol. I, p. 338–353. The following classes of materials are covered: I. Structure of Alloys. II. Non-ferrous Metals and Alloys. III. Iron and Steel. IV. Worked Metals and Alloys. V. Orientation of Crystals in Electrodeposited Metals. VI. Fibrous or Deformed Substances. VII. Cellulose and Related Compounds. VIII. Rubber and Related Compounds. IX. Ceramic Materials and Products. X. Glass and Silica. XI. Catalysts. XII. Amorphous and Colloidal Materials. XIII. Application to the Identification of Compounds.

I. Structure of Alloys

(1) Hadfield, Main and Brooksbank, *83*, **15 II**: 72; 20 (steels). (2) Bain, *33*, **25**: 657; 21 (crystal structure). (3) Bain, *80*, **68**: 625; 23 (crystal structure of solid solutions). (4) Wever, *Bericht No.* 24 *des Werkstoffausschusses der Ver. deutscher Eisenhüttenleute*, Oct. 5, 1922 (structure of metals). (5) Jeffries and Archer, *33*, **29**: 923, 966; 23 (solid solutions). (6) Rosenhain, *58*, **112**: 832; 23 (solid solutions and inter-metallic compounds). (7) Rosenhain, *115*, **115**: 591; 23 (inner structure of alloys). (8) St. John, *430*, **112**: 890, 908; 23 (X-rays in the steel industry). (9) Bain, *45*, **16**: 692; 24 (X-ray crystal analysis in metallurgy).

(10) Becker, *Metallbörse*, **14**: 297, 346, 395, 442; 24 (X-rays in chemical research). (11) Andrew, *J. Roy. Tech. Coll. Glasgow*, No. **2**: 63; 25 (crystalline structure of metals). (12) Czochralski, *218*, **13**: 425, 455; 25. *95*, **17**: 1; 25 (metallography and physical research). (13) Glöcker, *95*, **16**: 180; 24 (testing of materials). (14) Jeffries, *66*, **25 I**: 444; 25 (X-ray metallography). (15) Rosenhain, *325*, **24**: 361; 25 (inner structure of alloys). (16) Weiss, *198*, **36**: 397; 25. *74*, **22**: 333, 450; 25 (X-ray spectrography and the study of metals). (17) Weiss, *5*, **108**: 643; 25 (X-rays and the study of alloys). (18) Westgren and Phragmén, *55*, Special No., April 1, 1925, p. 86 (structure of alloys). (19) Westgren, *Sartryck ur Teknisk Tidsk.*, 1925, häft 22 (solid solutions).

(20) Aborn and Burgmann, *The Tech Engineering News*, April, 1926, p. 2 (ultimate structure of metals). (21) Rinne, *95*, **18**: 37, 81; 26 (models for the mechanics of metals). (22) Tammann, *8*, **79**: 81; 26 (distribution of two kinds of atoms in mixed crystals). (23) Westgren and Phragmén, *95*, **18**: 279; 26 (metallic systems). (24) Westgren and Phragmén, *20*, **19B**: No. 12; 26 (structure analogies of alloys).

II. Structures of Non-Ferrous Metals and Alloys

(1) Imai, *159*, **11**: 313; 22 (Cu-Zn). (2) McKeehan, *Ann. Postes, Télég. Téléph*, **12**: 1303; 23. *47*, **32**: 564; 24 (K, Be, BeO, and Ag-Pd and Au-Ag alloys). (3) Davey, *2*, **26**: 736; 25 (W). (4) Johansson and Linde, *8*, **78**: 439; 25 (Au-Cu and Pd-Cu). (5) Krüger and Sacklowski, *8*, **78**: 72; 25 (Pd-Ag alloys containing H). (6) Anderson, *143*, **201**: 465; 26 (duralumin and its crystal structure). (7) Bradley and Ollard, *58*, **117**: 122; 26 (Cr). (8) Freeman and Brandt, *31A*, **20**: 661, 695; 26 (Zn). (9) Friauf, *1*, **48**: 1906; 26 (magnesium plumbide).

(10) Harang, *63*, **27**: 204; 26 (Heusler alloys). (11) Holgersson, *8*, **79**: 35; 26 (Au-Ag and Ni-Cu). (12) Sillers, *31A*, **20**: 686; 26. *Cf.* Pierce, Anderson and Van Dyck, *143*, **200**: 363; 25 (Zn). (13) Westgren and Phragmén, *468*, **2**; 1926 (Cr-C). (14) Westgren and Phragmén, *93*, **156**: 27; 26 (W-C and Mo-C).

III. Crystal Structure of Iron and Steel

Cf. vol. I, p. 349

(1) Iokibe, *159*, **9**: 275; 20 (graphite and temper-carbon from cast iron). (2) Westgren, *220*, **105**: 401; 21 (steel). (3) Westgren, *140*, **103**: 303; 21. *115*, **111**: 727, 757; 21 (iron and steel). (4) Westgren and Lindh, *7*, **98**: 181; 21 (iron and steel). (5) Wever, *226*, **3**: 45; 21 (arrangement of iron atoms in austenitic steel). (6) Bain, *33*, **26**: 543; 22 (martensite formed spontaneously from austenite). (7) Tammann, *77*, **42**: 772; 22 (transformation of cementite at 210°). (8) Westgren and Phragmén, *140*, **105**: 241; 22 (steel). (9) Westgren and Phragmén, *7*, **102**: 1; 22 (iron and steel).

(10) Wever, *226*, **4**: 67; 22 (iron carbide). (11) Wever, *226*, **4**: 81; 22 (graphite and temper-carbon). (12) Bain and Jeffries, *430*, **112**: 805; 23 (red hardness in high-speed steel). (13) Heaps, *2*, **22**: 486; 23 (crystal structure and magneto-striction). (14) Okochi, *469*, **2**: 13; 23 (brittleness in electrolytic iron). (15) Westgren and Phragmén, *220*, **1923**: 449 (steel). (16) Zorning, *471*, **4**: 77; 23 (examination of steel by X-ray spectrometer). (17) Bain, *80*, advance copy, Feb., 1924 (martensite). (18) Greene, *430*, **114**: 615, 670; 24 (troostite and sorbite). (19) Heindlhofer, *2*, **24**: 426; 24 (martensite).

(20) Heindlhofer and Wright, *212*, **7**: 34; 24 (hardened ball steel). (21) Honda, *212*, **6**: 187; 24 (transformation in pure Fe). (22) Lucas, *212*, **6**: 669; 24 (austenite and martensite). (23) Westgren and Phragmén, *58*, **114**: 94; 24. *140*, **109**: 159; 24 (steel). (24) Wever, *9*, **30**: 376; 24 (technical iron). (25) Wever and Rütten, *226*, **6**: 1; 24 (solid solution γ-Fe-C). (26) Williams, *417*, **13**: 175; 24 (hardened steel). (27) Benedicks, *58*, **115**: 230; 25 (hardness of Mn-steel). (28) Foley, *80*, **73**: 850; 26 (amorphous cement and the formation of ferrite). (29) Honda, *159*, **14**: 165; 25 (formation of martensite in C-steels).

(30) Wever, *77*, **45**: 1208; 25 (Fe). (31) Davey, *120*, **29**: 440; 26 (iron and steel). (32) Fink and Campbell, *212*, **9**: 717; 26 (influence of heat treatment and carbon content on pure Fe-C alloys). (33) Osawa, *140*, **113**: 447; 26 (lattice-constant and density of Fe-Ni alloys). (34) Phragmén, *140*, **1926**, advance paper (Fe-Si alloys).

IV. X-ray Diffraction of Worked Metals and Alloys

(1) Owen and Blake, *58*, **92**: 686; 14 (metallic crystals). (2) Schmidt, *63*, **17**: 554; 16 (metals). (3) Gross and Blassmann, *190B*, **42**: 728; 19 (wire-forming W crystals). (4) Nishikawa and Asahara, *2*, **15**: 38; 20 (metals). (5) Bain and Jeffries, *33*, **25**: 775; 21 (mixed orientation in crystals of ductile metals). (6) Ettisch, Polanyi and Weissenberg, *65*, **22**: 646; 21 (metals). (7) Ettisch, Polanyi and Weissenberg, *96*, **7**: 181; 21 (fibre-structure of Cu and W-wires). (8) Ettisch, Polanyi and Weissenberg, *7*, **99**: 332; 21 (fibrous structure of hard-drawn metals). (9) Kirchner, *8*, **69**: 59; 22 (experiments on structure).

(10) Mark, Polanyi and Schmid, *96*, **12**: 58, 78, 111; 22 (drawing Zn crystals). (11) Niwa and Matûra, *338*, **122**: 1; 22 (cold rolling of sheet steel). (12) Ono, *470*, **2**: 261; 22 (inner structure of strained metals). (13) Ono, *470*, **2**: 241; 22 (inner structure of strained Cu-wire). (14) Polanyi, *218*, **10**: 411; 22 (crystal arrangement). (15) Polanyi, *9*, **28**: 16; 22 (fixing single crystals). (16) van Arkel, *208*, **3**: 76; 23 (uni-crystalline W). (17) Bain, *33*, **28**: 65; 23 (cored crystals and metallic compounds). (18) Czochralski, *95*, **15**: 60, 126; 23 (structure hypotheses). (19) Kakinuma, *219*, **5** 90; 23 (atomistic mechanism of metal rolling).

(20) Mark and Polanyi, *96*, **18**: 75; 23 (space-lattice, gliding directions and gliding planes in white Sn). (21) Mark, Polanyi and Schmid, *218*, **11**: 256; 23 (uni-crystalline Sn-wires). (22) Mark and Weissenberg, *96*, **16**: 314; 23 (rolled metal foils). (23) Mark and Weissenberg, *96*, **14**: 328; 23 (rolled metal foils). (24) Müller, *5*, **105**: 500; 24 (crystal axes in "single-crystal" Al-bars). (25) Polanyi, *96*, **17**: 42; 23 (structure changes through cold working). (26) Polanyi and Weissenberg, *97*, **4**: 199; 23 (worked metals). (27) Thomassen, *95*, **15**: 306; 23 (surface layer of worked metals). (28) Bragg, *58*, **113**: 639; 24 (metal film). (29) Research Staff of General Electric Co., *3*, **48**: 800; 24 (deformation of W single crystals).

(30) Glöcker and Kaupp, *95*, **16**: 377; 24 (recrystallization of Ag). (31) Gross, *95*, **16**: 18; 24. *47*, **31**: 385; 24 (deformed crystals and the process of work-hardening). (32) Kakinuma, *219*, **5**: 150; 24 (atomistic mechanism of metal rolling). (33) Lester, *471*, **5**: 455; 24 (crystal deformation in cold-worked steel). (34) Polanyi, *97*, **5**: 580; 24 (worked metals). (35) Schiebold, *95*, **16**: 417, 462; 24 (hardening phenomena in metals). (36) Wever, *96*, **28**: 69; 24 (cubically crystallizing metals after rolling). (37) Anderson and Norton, *80*, **71**: 720; 25 (evidence versus the amorphous-metal hypothesis). (38) van Arkel, *208*, **5**: 208; 25. *218*, **13**: 662; 25 (deformation of lattice of metals). (39) Clark, Brugmann and Heath, *45*, **17**: 1142; 25 (ultimate structures of commercial metals).

(40) Davey, *50*, **29**: 1211; 25 (plasticity of single crystals). (41) Elam, *115*, **120**: 368; 25 (orientation of crystals produced by heating strained Fe). (42) Fujiwara, *429*, **8A**: 339; 25 (arrangement of micro-crystals in Al-wire). (43) Glöcker, *96*, **31**: 386; 25 (deformation and recrystallization structures). (44) Glöcker, Kaupp and Widmann, *95*, **17**: 353; 25 (recrystallization of rolled plate Ag). (45) Leonhardt, *94*, **61**: 100; 25 (Laue diagrams of deformed crystals). (46) Lester and Abron, *471*, **6**:120, 200; 25 (Fe-crystals in steel under stress). (47) Mark, *94*, **61**: 75; 25 (growth and deformation structures). (48) Norton and Anderson, *2*, **25**: 582; 25 (cold-worked and burnished metals). (49) Ono, *470*, **3**: 195; 25 (Cu and Al under extension, compression and torsion).

(50) Ono, *470*, **3**: 267; 25 (α-Fe plastically strained in extension, compression and torsion). (51) Ono, *470*, **3**: 287; 25 (crystal rearrangement and the cause of strain-hardening). (52) Polanyi, *95*, **17**: 94; 25 (crystal deformation

and hardening). ([53]) Polanyi, *94*, **61**: 49; 25 (deformation of single crystals). ([54]) Polanyi and Schmid, *96*, **32**: 684; 25 (solidification and melting of Sn). ([55]) Sachs and Schiebold, *98*, **69**: 1557, 1601; 25 (volume compression of Al). ([56]) Sachs and Schiebold, *218*, **18**: 964: 25 (lattice lengths of deformed single crystals and crystal aggregates). ([57]) Seidl and Schiebold, *95*, **17**: 221, 320, 365; 25 (inhomogeneous Al-castings on cold rolling). ([58]) Tanaka, *429*, **8A**: 319; 25 (rolled Pt-plate). ([59]) Taylor and Elam, *5*, **108**: 28; 25 (plastic extension and fracture of Al-crystals).

([60]) Carpenter, *440*, **28**: 543, 575; 26. **29**: 31, 26 (single crystals). ([61]) Elam, *5*, **112**: 289; 26 (tensile tests of large Au, Ag and Cu-crystals). ([62]) Frölich, Clark and Aborn, *Mass. Inst. Tech. Publications*, **61**: 239; 26. *78*, **49**: preprint; 26 (lead deposits). ([63]) Owen and Preston, *67*, **38**: 132; 26 (effect of rolling on crystal structure of Al). ([64]) Schiebold and Sachs, *94*, **63**: 34; 26 (growth of Al-crystals during recrystallization). ([65]) Smithells, Rooksby and Pitkin, *47*, **1926**: advance paper (deformation of W-crystals).

V. Orientation of Crystals in Electrodeposited Metals

([1]) Glöcker and Kaupp, *96*, **24**: 121; 24 (fibrous structure). ([2]) Clark and Frölich, *9*, **31**: 655; 25 (electrolytic Ni). ([3]) Bozorth, *2*, **26**: 390; 25 (orientation of crystals in electrodeposited metals).

VI. Fibrous or Deformed Substances

([1]) Friedrich, *63*, **14**: 317; 13 (X-ray interference in non-crystalline bodies). ([2]) Nishikawa and Ono, *219*, **7**: 131; 13 (transmission of X-rays through fibrous, lamellar and granular substances). ([3]) Nishikawa, *219*, **7**: 296; 14 (spectrum of X-rays obtained by lamellar or fibrous substances). ([4]) Becker, Herzog, Jancke and Polanyi, *96*, **5**: 61; 21 (arrangement of crystal elements). ([5]) Herzog, *218*, **12**: 955; 24 (fine structure of fibrous materials). ([6]) Rinne, *94*, **59**: 230; 24 (rearrangement and decomposition of crystal structures). ([7]) Rinne, *189*, No. **17**: 513; 24 (permanent structural deformation of graphite). ([8]) Schmid, *96*, **22**: 328; 24 (plastic deformation of crystals). ([9]) Rinne, *189*, **1925**: 225 (optical anomalies).

([10]) Rinne, *218*, **13**: 690; 25 (paracrystalline and stressed substances). ([11]) Rinne, *94*, **61**: 389; 25 (flow of natural salts). ([12]) Sachs and Schiebold, *95*, **17**: 400; 25 (melting and recrystallization). ([13]) Herzog, *472*, **24**: 137; 26 (fibrous substances). ([14]) Levitskii, *96*, **35**: 850; 26 (bending of rock-salt in air and water). ([15]) Ranzi, *59*, **3**, No. **3**: 135; 26 (changes in reticular distances of rock-salt and calcite).

VII. Cellulose and Related Compounds

([1]) Herzog and Jancke, *96*, **3**: 196; 20 (cellulose). ([2]) Herzog, Jancke and Polanyi, *96*, **3**: 343; 20 (cellulose). ([3]) Herzog, *473*, **2**: 101; 21 (cellulose). ([4]) Herzog and Jancke, *92*, **34**: 385; 21 (cellulose). ([5]) Herzog, *472*, **21**: 388; 23 (deformation of cellulose). ([6]) Hess, Weltzien and Messmer, *13*, **435**: 1; 23 (cellulose). ([7]) Sponsler, *223*, **5**: 757; 23 (structural units of starch). ([8]) Gonell, *96*, **25**: 118; 24 (cellulose). ([9]) Katz, *63*, **25**: 659; 24 (X-ray spectroscopy and swelling).

([10]) Katz, *63*, **25**: 321; 24 (swelling of substances giving fibrous diagram). ([11]) Katz, *63*, **25**: 659; 24 (X-ray methods and imbibition). ([12]) Katz and Mark, *64V*, **33**: 294; 24 (swelling). ([13]) Sponsler, *2*, **23**: 662; 24 (X-ray reflection from very thin crystals). ([14]) Vieweg, *25*, **57B**: 1917; 24 (aqueous and dilute alcoholic NaOH and cellulose). ([15]) Herzog, *473*, **6**: 39; 25 (constitution of cellulose). ([16]) Herzog, *472*, **23**: 121; 25 (significance of fine structure of cellulose fiber in purification process). ([17]) Katz, *473*, **6**: 37; 25 (celluloses of different degrees of polymerization). ([18]) Katz, *473*, **6**: 35; 25 (X-ray data and alkali adsorption of cellulose). ([19]) Katz and Mark, *9*, **31**: 105; 25 (X-ray diffraction patterns of cellulose hydrate and its reversion products).

([20]) Katz and Mark, *7*, **115**: 385; 25 (changes in powder pattern of cellulose due to swelling). ([21]) Katz and Vieweg, *9*, **31**: 157; 25 (X-ray diffraction patterns and the alkali content during swelling of cellulose). ([22]) Herzog, *37*, **9**: 631; 26 (acetyl- and nitro-cellulose). ([23]) Herzog, *Pulp Paper Mag. Can.*, **24**: 699; 26 (colloidal characters of cellulose). ([24]) Herzog, *55*, **39**: 98; 26 (swelling of cellulose). ([25]) Herzog, *Pulp Paper Mag. Can.*, **24**: 694; 26. *Paper Trade J.*, **83**, No. **1**: 51; 26 (cellulose). ([26]) Herzog, *50*, **30**: 457; 26 (significance of structure of cellulose in chemical transformation). ([27]) Herzog and Gonell, *92*, **39**: 380; 26 (weighting of silk). ([28]) Katz, *9*, **32**: 269; 26 (inflation and mercerization of cellulose). ([29]) Ott, *37*, **9**: 378; 26 (crystalline character of acetyl-cellulose).

VIII. Rubber and Related Compounds

([1]) Davey, *2*, **21**: 719; 23 (ZnO in vulcanized rubber). ([2]) Pummerer, Koch and Gross, *13*, **435**: 294; 24 (crystalline rubber and hydrorubber). ([3]) Hauser and Mark, *Kautschuk*, Dec., 1925 (elongated samples of rubber). ([4]) Katz, *55*, **36**: 300: 25. **37**: 19; 25. *218*, **30**: 410; 25 (changing of X-ray spectrum of rubber on stretching). ([5]) Katz, *136*, **49**: 353; 25 (rubber under different degrees of elongation). ([6]) Katz and Bing, *92*, **38**: 439; 25 (Is raw rubber partially crystallized?). ([7]) Katz and Bing, *92*, **38**: 545; 25 (rubbers containing inorganic ingredients). ([8]) Clark, *45*, **18**: 1131; 26 (rubber and allied materials). ([9]) Hauser, *456*, **40**: 2090; 26 (origin of interference in stretching of rubber).

([10]) Hauser and Mark, *287*, **Ambronn-Festschrift**: 64: 26 (stretched rubber). ([11]) Hauser and Mark, *287*, **22**: 63; 26 (stretched rubber). ([12]) Ott, *218*, **14**: 320; 26 (size of rubber and gutta-percha molecules).

IX. Ceramic Materials and Products

([1]) Hadding, *Lunds Universitets Årsskrift*, **14**: No. 23; 18. *Mineral. Abstr.*, **2**: 205 (feldspar). ([2]) Hadding, *Lunds Universitets Årsskrift*, **17**: No. 6; 20 (feldspar). ([3]) Kozu and Endō, *159*, **1 III**: 1; 21 (andularia and moonstone). ([4]) Bragg, Shearer and Mellor, *82*, **22**: 105; 23 (china clays). ([5]) Schwarz and Brenner, *25*, **56B**: 1433; 23 (synthetic aluminum silicate). ([6]) Rinne, *218*, **12**: 244; 24 (lead-pencil marks). ([7]) Schwarz, *105*, **8**: 298; 24. *103*, **32**: 538; 24 (formation of kaolin). ([8]) Shearer, *82*, **23**: 314; 24 (china clays). ([9]) Sielakov, *74E*, **21**: 527; 24 (clays).

([10]) Hadding, *82*, **24**: 27; 25 (clays). ([11]) Research Staff of General Electric Co., *82*, **24**: 402; 25 (constitutional changes occurring in clays on heating). ([12]) Navias, *38*, **8**: 296; 25 (development of mullite in fired clays). ([13]) Navias and Davey, *38*, **8**: 640; 25 (mullite and sillimanite). ([14]) Norton, *38*, **8**: 401; 25 (natural and artificial sillimanite). ([15]) Norton, *38*, **8**: 636; 25 (cyanite and andalusite). ([16]) Rinne, *103*, **33**: 427, 459, 525; 25 (X-ray and ceramics). ([17]) Rinne, *94*, **61**: 113; 25 (calcined calcite, dolomite, kaolinite and mica). ([18]) Bowen and Wyckoff, *128*, **16**: 178; 26 (thermal dissociation of dumortierite). ([19]) Greig, *38*, **8**: 465; 25. *12*, **11**: 1; 26 (mullite from cyanite, andalusite and sillimanite).

([20]) Mark and Rosbaud, *190B*, **54**: 127; 26 (Al_2SiO_5 and pseudobrookite). ([21]) Rosbaud, *9*, **32**: 317; 26 (aluminum silicate). ([22]) Wyckoff, Greig and Bowen, *12*, **11**: 459; 26 (mullite and sillimanite).

X. Glass and Silica

([1]) Kyropoulos, *93*, **99**: 197, 249; 17 (various kinds of silica). ([2]) Miller, *5*, **101**: 515; 22 (vitreous silica). ([3]) Washburn and Navias, *197*, **8**: 1; 22 (chalcedony and other forms of silica). ([4]) Selyakov and Strutinskii, *Mitt. wiss.-tech. Arbeiten in der Republik (Russ.)*, **13**: 18; 24 (structure of glass). ([5]) Selyakov, Strutinskii and Krasnikov, *96*, **33**: 53; 25 (structure of glass). ([6]) Wyckoff and Morey, *105*, **9**: 256; 25 (soda-lime-silica glasses).

XI. X-ray Data Applied to Problems of Catalysis

([1]) Clark, Asbury and Wick, *1*, **47**: 2661; 25 (structure of nickel catalysts). ([2]) Levi, *22*, **2**: 419; 25 (thorium oxide and the dehydration of alcohol). ([3]) Wyckoff and Crittenden, *1*, **47**: 2866; 25 (ammonia catalysts). ([4]) Levi and Haardt, *36*, **56**: 424; 26 (catalytic action considered as that of surfaces). ([5]) Levi and Haardt, *22*, **3**: 91; 26 (catalytic action of metals of the Pt group). ([6]) Levi and Haardt, *22*, **3**: 215; 26 (catalytic action of metals of the Pt group).

XII. Amorphous and Colloidal Materials

([1]) Asahara, *210*, **1**: 23; 22. *209*, **1**: 35; 22 (graphite and amorphous C). ([2]) Haber, *25*, **55B**: 1717; 22 (amorphous precipitates and crystallized sols). ([3]) Kustner, *96*, **10**: 41; 22 (decomposition and rebuilding of gadolinites). ([4]) Mulligan, *50*, **26**: 247; 22 (dehydration of crystalline aluminum hydroxide). ([5]) Böhm and Niclassen, *93*, **132**: 1; 23 (amorphous precipitates and crystallized sols). ([6]) Fricke and Wever, *93*, **136**: 321; 24 (aging of precipitated metal hydroxides). ([7]) Rinne, *94*, **60**: 55; 24 (finely divided minerals, artificial products and dense rocks). ([8]) Baudisch and Welo, *141*, **64**: 753; 25 (aging of ferrous hydroxide and ferrous carbonate). ([9]) Böhm, *93*, **149**: 203; 25 (aluminum hydroxide and iron hydroxide).

([10]) Böhm, *93*, **149**: 217; 25 (glowing of oxides of certain metals). ([11]) Herzog, *55*, **37**: 355; 25 (colloid systems). ([12]) Herzog and Gonell, *25*, **58B**: 2228; 25 (collagen). ([13]) Katz and Gerngross, *218*, **13**: 900; 25 (gelatin and collagen). ([14]) Levi, *216*, **7**: 410; 25 (new chemical studies). ([15]) Ruff, Schmidt and Olbrich, *93*, **148**: 313; 25 (amorphous C and graphite). ([16]) Welo and Baudisch, *141*, **65**: 215; 25 (catalytically active and inactive forms of Fe_2O_3). ([17]) Welo and Baudisch, *166*, **62**: 311; 25 (oxides of iron in new catalytic actions). ([18]) Gutbier, Hüttig and Dobling, *25*, **59B**: 1232; 26 (stannic oxide-water). ([19]) Herzog and Krüger, *218*, **14**: 599; 26 (dispersibility of organic colloids).

([20]) Posnjak, *50*, **30**: 1073; 26 (stannic acids).

XIII. Application to the Identification of Compounds

([1]) Posnjak and Merwin, *1*, **44**: 1965; 22 (Fe_2O_3-SO_3-H_2O). ([2]) Schleede and Gruhl, *9*, **29**: 411; 23 (luminescent zinc silicate). ([3]) Kohlschütter and Scherrer, *37*, **7**: 337; 24 (polymorphism in lead oxide). ([4]) Levi and Quilico, *36*, **54**: 598; 24 (non-existence of Ag suboxide). ([5]) Shaxby, *34*, **179**: 1602; 24 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). ([6]) Volmer, *13*, **440**: 200; 24 ($HClO_4.H_2O$ and NH_4ClO_4). ([7]) Jung, *93*, **142**: 73; 25 (dehydration products of gypsum). ([8]) Levi, *216*, **7**: 410; 25 (new chemical studies). ([9]) Levi and Tacchini, *36*, **55**: 28; 25 (non-existence of Ni suboxide).

([10]) Linck and Jung, *93*, **147**: 288; 25 (black metallic P). ([11]) Shaxby, *3*, **49**: 1201; 25 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). ([12]) Sosman and Posnjak, *128*, **15**: 329; 25 (ferromagnetic ferric oxide). ([13]) Ewles, *Proc. Leeds Phil. Lit. Soc.*, **1**: 6; 26 (luminescence of solids). ([14]) Frebold, *187*, **23**: 115; 26 (iron hydroxide ores).

PROPERTIES OF METALS AND ALLOYS

W. ROSENHAIN, SPECIAL EDITOR

F. P. UPTON, EDITORIAL ASSISTANT

INTRODUCTION

The very condensed form in which it has been necessary to present the metallurgical data in the tables, requires some explanation in regard to their use. The abbreviations and special symbols used are explained on p. 392 and some examples illustrating their interpretation in particular cases are given below.

A table of "Critical Values" of the mechanical properties of metals and alloys necessarily differs in certain important respects from the "Critical Values" given in other connections. The reason is that metallurgical products, particularly of the more complex sort, are subject to certain unavoidable variations even when produced under the best conditions. In regard to

INTRODUCTION

Etant donné la forme très condensée dans laquelle il a été nécessaire de présenter les données métallurgiques dans les tables, il est indispensable de donner quelques explications pour leur emploi. Les abréviations et les symboles spéciaux utilisés sont expliqués à la p. 392, et quelques exemples illustrant leur interprétation dans des cas particuliers sont donnés ci-dessous.

Une table de "valeurs critiques" des propriétés mécaniques des métaux et alliages diffère nécessairement sous certains rapports importants des "valeurs critiques" données pour d'autres sujets. La raison en est que les produits métallurgiques, et plus particulièrement ceux qui sont les plus complexes, sont sujets à certaines varia-

EINLEITUNG

Die äusserst knappe Form in welcher die Metallurgie notwendigerweise in den Tafeln dargelegt ist, erfordert für ihren Gebrauch einige Erklärungen. Die vorkommenden Abkürzungen und besondere Symbole sind Seite 392 erklärt. Einige Beispiele zu ihrer Verständnis in besonderen Fällen sind weiter unten angegeben.

Eine Tafel der "Kritischen Werte" der mechanischen Eigenschaften von Metallen und Legierungen, weicht in gewissen wichtigen Beziehungen von den "Kritischen Werten" anderer Arten ab.

Dies ruht daher dass metallurgische Produkte, besonders solche komplexerer Art, gewissen unvermeidlichen Eigenschaftsschwank-

INTRODUZIONE

La forma molto condensata in cui è stato necessario esporre i dati metallurgici richiede alcune spiegazioni circa l'uso delle tabelle. A pag. 392 sono spiegate le abbreviazioni e i simboli speciali adoperati, e più avanti sono riportati alcuni esempi illustranti la loro interpretazione in casi particolari.

Una tabella di "valori critici" delle proprietà meccaniche di metalli e leghe differisce necessariamente sotto alcuni punti di vista importanti dai "valori critici" di altre proprietà, e ciò per il fatto che i prodotti metallurgici, specie quelli più complessi, sono soggetti a variazioni inevitabili, anche se ottenuti nelle migliori condizioni. Per molti metalli e leghe i valori riportati

many of the metals and alloys mentioned in the tables the origin of the data varies widely, some being derived from numerous tests on industrial products, while others represent the results of laboratory investigation. In making use of the tables, therefore, it is necessary to ascertain the nature of the data given. This can always be done by reference to the literature quoted. While laboratory results are generally accurately determined, it must be borne in mind that they may be either higher or lower than the figures to be anticipated from a corresponding industrial product. In some instances large-scale production makes it possible to secure better results than can be obtained in relatively small laboratory experiments, while in other cases the special conditions which can be used in laboratory work cannot readily be reproduced in industrial production.

If it is desired to form an opinion of the value of a given material for constructional purposes the nature of the material must be considered. In the case of castings, wide variations in mechanical properties occur as between different parts of the same casting, as between a large and small casting, and as between actual castings and test bars prepared either at the same time or otherwise. Even in a casting of given shape and material, variations in casting conditions, such as pouring temperature, rate of pouring and mold temperature, may cause considerable differences in mechanical properties. The figures quoted in the tables must therefore be regarded as indicating the values found for cast materials under conditions specified in the corresponding literature, and cannot be used, without further consideration, for the purpose of calculating the reliable strength of a particular casting. In wrought material, variations are likely to be much smaller than in cast. However, complete uniformity cannot be relied upon, particularly as between the products of different makers. In regard to some materials which are extensively produced industrially, the data given in the tables sometimes represent the values obtained from very numerous tests. In other cases the data may represent only isolated experiments. In compiling the tables, care has been taken to incorporate as far as possible only the most reliable data of both kinds.

Another cause of considerable variation in the mechanical properties of metals and alloys, in the wrought state, arises from the effect of mass. Material in large sections is in almost every case weaker than the same material produced in small sections. This is particularly marked where heat treatment of any kind has been given. Where the data in the tables include values corresponding to materials of different sections, it will obviously be desirable to attach the greatest importance to those figures relating to materials which have a cross section similar to that which it is proposed to use, or whose properties it is desired to ascertain. It should also be borne in mind that there is a steady improvement in foundry, rolling mill, forging and heat-treating practice, so that, as a rule, the more modern methods yield values superior to those of older materials.

In the use of the tables three possibilities will arise: (I) The properties of an alloy whose composition is known are desired. (II) The properties of some commercial alloy whose composition is not known are desired. (III) An alloy having certain properties is desired.

I. Composition of Alloy Known. Properties Desired

1. Turn to the Table of Contents (p. 358), and ascertain the section in which this type of alloy is treated.

2. Turn to the section at the page number given.

3. With the aid of the Table of Contents at the beginning of the section, ascertain the table containing the desired type of information and turn to it.

4. In each table (unless otherwise indicated) the alloys are arranged in the order of their "type formulae." The type formula

tions inévitables, même lorsqu'ils ont été fabriqués dans les meilleures conditions. L'origine des données se rapportant a plusieurs des métaux et alliages mentionnées dans les tables varie dans une large mesure; certaines données proviennent de nombreux essais sur des produits industriels alors que les autres représentent les résultats d'expériences de laboratoire. C'est pourquoi il est nécessaire pour l'emploi des tables de s'assurer de la nature des valeurs données. Ceci peut toujours être réalisé en se référant à la source bibliographique citée. Les résultats de laboratoire sont généralement déterminée avec précision; il ne faut pas cependant perdre de vue qu'ils peuvent être ou supérieurs ou inférieurs aux chiffres qu'on peut attendre d'un produit industriel correspondant. Dans certains cas une production sur une large échelle permet l'obtention de meilleurs résultats que ceux qui peuvent être obtenus dans des expériences effectuées dans le laboratoire, alors que dans d'autres cas, les conditions spéciales qui peuvent être utilisées dans le travail de laboratoire ne sont pas reproductibles facilement dans une production industrielle.

Si l'on désire se faire une opinion de la valeur d'une matière donnée et cela pour des buts de construction, il faut considérer la nature de la matière. Dans le cas des pièces fondues, il existe de grandes variations dans les propriétés mécaniques aussi bien entre les différentes parties d'une pièce donnée qu'entre une grande ou une petite pièce ou qu'entre une pièce donnée et des éprouvettes préparées au même moment ou plus tard. Même pour une pièce de dimension et d'une matière données, les variations dans les conditions de coulée, telle que la température de coulée, la vitesse de coulée et la température du moule, peuvent occasionner des différences considérables dans les propriétés mécaniques. Les chiffres cités dans les tables doivent donc être regardés comme indiquant les valeurs trouvées pour des matières coulées dans des conditions spécifiées dans la littérature correspondante, et ils ne peuvent être utilisés sans autres considérations, dans le but de calculer une valeur de résistance digne de confiance d'une pièce coulée particulière. Dans les matières travaillées, les variations sont ordinairement plus petites que dans les matières fondues. Cependant, on ne peut pas tabler sur une complète uniformité, surtout entre des produits de différents fabricants. En ce qui concerne certaines matières qui sont produites industriellement en grand, les valeurs données dans les tables représentent quelquefois les valeurs obtenues dans de très nombreux essais. Dans d'autres cas, les valeurs peuvent ne représenter que des expériences isolées. En établissant les tables, il a été pris soin de n'incorporer autant que possible que les valeurs des deux sortes les plus dignes de confiance.

Une autre cause, occasionnant une variation considérable dans les propriétés mécaniques des métaux et alliages à l'état travaillé, est produite par l'effet de la masse. Une matière de grande section est dans presque chaque cas plus faible que la même matière produite en petites sections. Ce fait est particulièrement marqué lorsqu'un traitement thermique quel qu'il soit a été effectué. Lorsque les données dans les tables comportent des valeurs correspondant à des matières de différentes sections, il sera évidemment préférable d'attacher la plus grande importance aux chiffres se rapportant aux matières ayant une section similaire à celle qu'on se propose d'utiliser, ou dont on désire connaître les propriétés. Il ne faut pas oublier non plus qu'il se produit une amélioration certaine dans les opérations de fonderie, de laminage, de forgeage et par les traitements thermiques de sorte qu'en règle générale, les méthodes les plus modernes conduisent à des valeurs supérieures à celles obtenues avec des matières fabriquées moins récemment.

Trois possibilités se présentent dans l'usage des tables: (I) On désire connaître les propriétés d'un alliage, dont la composition est connue. (II) On désire connaître les propriétés d'un alliage commercial dont la composition n'est pas connue. (III) On

ungen unterworfen sind, selbst wenn die Herstellungsbedingungen die besten waren. Bezüglich der vielen in den Tabellen angeführten Metallen und Legierungen, sind die Quellen aus welchen die Daten entnommen worden sind, sehr verschieden. Einige Daten sind von vielen Materialsprüfungen an Industrieprodukten abgeleitet, andere wieder, stellen das Ergebnis von Laboratoriumsuntersuchungen dar. Beim Gebrauche der Tafeln ist daher die Feststellung der Natur der Daten notwendig, was immer an Hand der angegebenen Literatur geschehen kann. Während im allgemeinen die Laboratoriumsergebnisse genau sind, muss man bedenken, das die Zahlenwerte bald höher bald niedriger sein können als die, welche an einem Industrie-Produkt zu erwarten sind. In mancher Hinsicht gestattet die Herstellung im Grossen, ein besseres Ergebnis als es in dem verhältnismässig kleinem Masstab des Laboratoriums möglich ist. In anderen Fällen wieder können die Bedingungen im Laboratorium nicht leicht bei der industriellen Herstellung eingehalten werden.

Ist es wünschenswert, dass man sich ein Bild über die Zahlenwerte eines gegebenen Materials für Konstruktionszwecke macht, so ist es notwendig die Natur des Materials zu berücksichtigen. Beim Guss weichen die mechanischen Eigenschaften sehr weitgehend an verschiedenen Stellen desselben Gusstückes von einander ab. Unterschiede sind sowohl zwischen einem in grossen oder kleinem Gusstuck als auch zwischen dem Hauptguss und dem Probestück vorhanden, wenn beide zugleich oder auf andere Weise hergestellt wurden. Sogar beim Giessen einer gegebenen Form und gegebenen Material, zeigen sich bemerkenswerte Differenzen der mechanischen Eigenschaften, wenn die Bedingungen beim Gusse, wie Gusstemperatur, Gussgeschwindigkeit, die Temperatur der Form, u. s. w., verändert werden. Es gelten daher die in den Tafeln angegebenen Zahlenwerte für ein gegossen hergestelltes Material nur unter den Bedingungen, welche in der entsprechenden Literatur angegeben sind. Die Zahlenwerte können jedoch nicht ohne weiteres zu dem Zwecke benützt werden, um einen zuverlässlichen Eigenschaftswert eines bestimmten Gusses zu berechnen. In bearbeitetem Material sind die Unterschiede häufiger viel kleiner als im gegossenen. Auf eine vollkommene Gleichheit ist nie zu rechnen, ganz besonders bei Materialien verschiedenen Ursprunges. In Bezug auf gewisse Materialien, welche ausgedehnt industriell hergestellt werden, stellen die angegebenen Werte manchmal die Ergebnisse sehr zahlreicher Prüfungen dar. In manchen anderen Fällen beziehen sich die Daten nur auf einzelne Untersuchungen. Bei der Zusammenstellung der Tafeln wurden soweit als möglich sorgfältig nur die verlässlichsten Daten, beider Typen aufgenommen.

Ein anderer Grund zur Änderung der mechanischen Eigenschaften von Metall und Legierung im bearbeiteten Zustand, kommt vom Einfluss der Masse her. Ein Material in grossen Stücken ist fast in allen Fällen weicher, als wenn dasselbe in kleineren Stücken hergestellt wird. Dies ist besonders bei einer Wärmebehandlung irgend welcher Art hervortretend. Wo in den Tafeln Werte vorhanden sind die sich auf Material-Stücke verschiedener Grösse beziehen, so wird es natürlich wünschenswert sein die grösste Wichtigkeit den Zahlen beizulegen, die sich auf ein herausgearbeitetes Stück beziehen, welches gleich dem Stück ist, welches benützt werden soll, oder dem Stück dessen Eigenschaften man kennen lernen will.

Man bedenke, dass in den Giessereien, Walzwerken, bei der Schmiedung und Wärmebehandlung ständig Fortschritte zu verzeichnen sind, so dass in der Regel die modernere Methoden ein Material liefern, dessen Eigenschafts-Werte den nach älteren Methoden hergestellten überlegen sind.

Beim Gebrauch der Tabellen können drei Möglichkeiten vorliegen: (I) Man sucht Eigenschaften einer Legierung bekannter Zusammensetzung. (II) Man sucht Eigenschaften einer

provengono da fonti notevolmente diverse: alcuni sono ricavati da numerosi saggi su prodotti industriali, mentre altri sono dedotti da ricerche di laboratorio. Nel servirsi delle tabelle è perciò necessario tener conto della natura dei dati, cosa che può sempre farsi riferendosi alla letteratura citata. I risultati di prove di laboratorio sono in genere accurati, e perciò essi possono essere più bassi o più alti dei valori prevedibili per un prodotto industriale corrispondente. In alcuni casi la produzione su larga scala rende possibile migliori risultati di quelli ottenibili in piccole prove di laboratorio, mentre in altri casi le condizioni speciali che si possono realizzare in laboratorio non si possono facilmente riprodurre nell'industria.

Per farsi una idea di un dato materiale a scopi costruttivi, se ne deve prendere in considerazione la natura. Nel caso di getti, ad es., si hanno ampie oscillazioni nelle proprietà meccaniche tra le diverse parti di uno stesso getto, come pure tra un getto grande e uno piccolo ed anche tra getti e provini, sia che questi vengano preparati assieme al getto sia che vengano ottenuti diversamente. Anche in un getto di forma e materiale determinati, eventuali differenze nelle condizioni di colata, come temperatura e velocità di colata, e temperatura della forma, possono produrre differenze notevoli nelle proprietà meccaniche. Perciò i valori delle tabelle indicano le proprietà del materiale quando questo sia ottenuto nelle condizioni specificate nella letteratura corrispondente ed essi non possono servire per calcolare senz'altro la resistenza probabile di un particolare getto. Nei materiali lavorati le variazioni sono spesso molto più piccole che in quelli ottenuti di getto; tuttavia non si può fare affidamento sopra una completa uniformità specie se si tratta di prodotti che hanno provenienza diversa. Per certi materiali che sono prodotti largamente nell' industria, i valori delle tabelle sono alcune volte ricavati da numerosissimi saggi; in altri casi invece essi rappresentano soltanto esperienze isolate. Nel compilare le tabelle si è avuto cura di servirsi il più che possibile solo dei valori dei due tipi che più sono degni di fiducia.

Considerevoli differenze nelle proprietà meccaniche dei metalli o leghe allo stato lavorato possono essere prodotti da effetto di massa. Un materiale in sezioni grandi è quasi sempre più debole che in sezioni piccole, e questo è particolarmente evidente nei casi in cui si è ricorso ad un trattamento termico qualunque. Quando nelle tabelle sono riportati valori corrispondenti a sezioni differenti, bisogna evidentemente attribuire la massima importanza ai numeri che si riferiscono a materiali con sezione simile a quella che si ha in animo di usare o di cui si vogliono stabilire le proprietà. Deve pure tenersi presente che vi è un continuo miglioramento nella pratica di fonderia di laminatoio, di fucina, e dei trattamenti termici per modo che, di regola, i metodi più moderni danno valori superiori a quelli dei materiali più antichi.

Nel servirsi delle tabelle tre casi si possono presentare: (I) Si può desiderare di conoscere le proprietà di una lega di cui è nota la composizione. (II) Si può desiderare di conoscere le proprietà di una lega commerciale di cui non è nota la composizione. (III) Si può desiderare di conoscere una lega che abbia determinate proprietà.

I. La composizione della lega è nota e si desidera conoscerne le proprietà

1. Si consulta l'indice a p. 358 e si vede quale è il capitolo in cui si parla di questo tipo di leghe.
2. Si consulta il capitolo alla pagina indicata.
3. Dall'indice che si trova al principio del capitolo si ricava la tabella che contiene il tipo di informazione che si desidera.
4. In ogni tabella (tranne che non sia indicato diversamente) le leghe sono disposte nell'ordine delle loro formule tipo. La formula tipo di una lega è costituita da dei simboli chimici dei suoi costituenti essenziali scritti in ordine decrescente della proporzione

of an alloy consists of the chemical symbols of its essential constituents written in descending order of their amounts in the alloy except in the case of steels, where C is written last. (*N. B.*—An element once thought merely incidental or an impurity in an alloy may later be found to have an important effect on its properties; *cf.* the case of silicon in duralumin.) Thus Pb-Sb-Cu is the type formula of alloys whose largest constituent (by weight) is Pb, the next largest Sb, and the next Cu; while a vanadium steel has the type formula Fe-V-C, although C is generally present in larger amounts than V. The different alloys are arranged in alphabetical order according to their type formulae.

Under a given type formula the alloys are arranged in descending order of the amounts of the principal constituent in the alloy, where this is given by analysis, and, where it is not given, then in ascending order of amounts of the second largest constituent in the alloy. Under each composition the data follow approximately in order of the extent of treatment given the alloy. Thus the properties of castings (symbol = G) appear first, then those of hot-worked material, and finally those of cold-worked material. The properties of heat-treated material follow immediately after those of the material before heat treatment.

Example 1: It is desired to compare the mechanical properties of a sand-cast 10% aluminum bronze with those of the same alloy in which 3% of the Al is replaced by Fe. It is desired to ascertain the properties of the alloys at high temperatures. The first alloy, call it "A," has the type formula Cu-Al; the second, call it "B," has the type formula Cu-Al-Fe. Turning to the Table of Contents (p. 359), we find that the section containing the mechanical properties of Al bronzes, begins on p. 572. Turning here we find a Table of Contents for the section in which are listed 15 tables of properties of the type Cu-Al and 6 tables of properties of the type Cu-Al-Fe.

Let us first consider the Ultimate Tensile Strength (*UTS*) in kg/mm², % Elongation (*El*) and Brinell Hardness Number (*BHN*) of our alloy "A" in the sand-cast (G_s) condition. From the tables we find as follows:

Table \ t, °C	*UTS* 20	*UTS* 500	*El* 20	*El* 500	*BHN* 20	*BHN* 500	Lit.
1	46–53		20		90–100		(13)
2	49.9		21.7				(3)
3	29.1	18.2	9.4	3.1			(2, 15)
4					76.7	<50	(12)
13	42.2		28.5		118		(26)
13	52.0		19.5		100		(7)

The values in Table 1 represent the average properties of alloy "A" and agree fairly well with those in the other tables excepting those in Table 3, which probably are for material cast under unsatisfactory conditions, a thing easily possible with aluminum bronze.

Considering alloy "B" in the same manner we have:

Table \ t, °C	*UTS* 20	*UTS* 500	*El* 20	*El* 500	*BHN* 20	*BHN* 500	Lit.
17	52.4		38.0		80		(10)
20	(Contains 7.6% Al, 2% Fe)				125	70	(12)

Although fewer data are available, alloy "B" seems to be as strong as and more ductile than "A" at 20°C, while the presence of 2% Fe has increased the hardness of the alloy at 500°C. Hardness figures of (12), however, are inconsistent with those from other sources. On the basis of the tables then, alloy "B" is somewhat the better alloy.

The index (p. 370) shows whether any commercial alloys of the composition of "B" are included. Index numbers of aluminum bronzes are listed in one of the tables of Alloy Classes following

désire un alliage ayant certaines propriétés. Les trois cas seront considérés dans l'ordre indiqué.

I. Composition de l'alliage connue. Propriétés désirées

1. Consulter la table des matières p. 358 et s'informer de la section dans laquelle il est traité de ce type d'alliage.
2. Consulter cette section à la page indiquée.
3. Au moyen de la table des matières se trouvant au commencement de la section, s'informer qu'elle est la table contenant le type d'information désiré et s'y porter.
4. Dans chaque table (à moins d'une autre indication) les alliages sont arrangés dans l'ordre de leur "formule type." La formule type d'un alliage se compose des symboles chimiques de ses constituants essentiels écrits dans l'ordre descendant de leurs proportions dans l'alliage, excepté pour le cas des aciers, où C est écrit en dernier. (*N. B.* Il peut se trouver qu'un élément dont la présence peut être considérée accidentelle ou une impureté dans un alliage peuvent avoir un effet important sur ses propriétés: par ex. cas du silicium dans duralumin). Ainsi Pb-Sb-Cu est la formule type des alliages dont le constituant le plus important (en poids) est Pb, celui qui vient ensuite dans le même ordre d'idée est Sb, et finalement vient Cu; un acier au vanadium aura la formule type Fe-V-C, quoique C soit généralement présent en plus grande quantité que V. Les différents alliages sont arrangés dans l'ordre alphabétique en accord avec leurs formules types.

Sous une formule type donnée, les alliages sont arrangés, lorsque ce résultat est fourni par l'analyse, dans l'ordre descendant des proportions de leur constituant principal dans l'alliage; lorsque l'analyse n'a pas été effectué, dans l'ordre ascendant des proportions du deuxième constituant en importance de l'alliage. Sous chaque composition, les données suivent approximativement dans l'ordre de la succession des traitements subis par l'alliage. Ainsi les propriétés des pièces fondues (symbole = G), sont mentionnées en premier. Ensuite viennent les propriétés de la matière travaillée à chaud et finalement celles de la matière travaillée à froid. Les propriétés de la matière traitée thermiquement suivent immédiatement celles de la matière avant le traitement thermique.

Exemple 1: On désire comparer les propriétés mécaniques d'un bronze d'aluminium à 10% Al coulé en sable avec celles du même alliage dans lequel 3% de l'Al ont été remplacés par Fe. On désire connaître les propriétés des alliages à hautes températures. Le premier alliage, désignons-le par "A," a la formule type Cu-Al; le second, désignons-le par "B" a la formule type Cu-Al-Fe. Consultant la table des matières (p. 359) on trouve que la section contenant les propriétés mécaniques des bronzes d'Al commence à p. 572. À cette page nous trouvons une table des matières pour la section, dans laquelle sont disposées en liste 15 tables des propriétés du type d'alliage Cu-Al et 6 tables des propriétés du type d'alliage Cu-Al-Fe.

Considérons d'abord: la charge de rupture (*UTS*) en kg/mm², l'allongement en % (*El*) et le nombre de dureté Brinell (*BHN*) de notre alliage "A" dans la condition "coulé en sable" (G_s). Des tables, on trouve:

Table \ t, °C	*UTS* 20	*UTS* 500	*El* 20	*El* 500	*BHN* 20	*BHN* 500	Lit.
1	46–53		20		90–100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	<50	(12)
13	42,2		28,5		118	–	(26)
13	52,0		19,5		100		(7)

Les valeurs dans la Table 1 représentent les propriétés moyennes de l'alliage "A;" elles s'accordent assez bien avec celles des autres

Legierung des Handels, unbekannter Zusammensetzung. (III) Man sucht eine Legierung von bestimmten Eigenschaften.

I. Die Zusammensetzung der Legierung ist bekannt. Eigenschaften gesucht

1. Man sehe im Inhaltsverzeichnis (S. 358) nach und stelle den Abschnitt fest in welchem diese Legierungstype behandelt wird.
2. Man schlage den Abschnitt an der gegebenen Seitenzahl auf.
3. Mit Hilfe des Inhaltsverzeichnisses am Anfang dieses Abschnittes, stelle man die Tafel fest, welche die gewünschte Type der Eigenschaften enthält und schlage diese Tafel dann auf.
4. In jeder Tafel (wenn nichts anderes angegeben ist) sind die Legierungen in der Reihenfolge ihrer "Typen-Formel" angeordnet. Diese "Typen-Formel" einer Legierung besteht in der Nebeneinandersetzung der chemischen Zeichen ihrer wesentlichen Bestandteile in absteigender Ordnung ihrer Prozentgehalte Eine Ausnahme ist bei den Stählen vorhanden, wo am Ende C steht. (*N. B.*—Ein Element, das zuweilen nur zufällig oder als Verunreinigung in den Legierungen vorhanden angesehen wurde, kann später als ein solches von besonderem Einfluss auf die Eigenschaft derselben erkannt werden, z. B. Si in Duralumin.) So ist Pb-Sb-Cu die Typenformel von Legierungen, in welchen Pb den höchsten Prozentgehalt darstellt, den nächst niedrigeren Sb, dann folgt Cu. Ein Vanadium-Stahl hat hingegen die Typenformel Fe-V-C, obwohl im allgemeinen C in grösserer Menge als V vorhanden ist. Die verschiedenen Legierungen sind in alphabetischer Reihenfolge ihrer Typenformeln angeordnet.

Unter einer gegebenen Typenformel sind die Legierungen in absteigender Ordnung des analytisch bekannten Hauptbestandteiles in der Legierung angeordnet. Ist dieser Gehalt nicht bekannt, so sind die Legierungen in aufsteigender Ordnung des Prozentgehaltes des zweiten grössten Bestandteiles angeordnet. Unter jeder Zusammensetzung folgen die Daten ungefähr nach der Zahl der verschiedenen Behandlungen, welchen die Legierung unterworfen wurde. So erscheinen die Eigenschaften des Gusses (Zeichen = G) zuerst, dann jene des heiss bearbeiteten und zum Schluss des kalt bearbeiteten Materials. Die Eigenschaften des wärmebehandelten Materials folgen unmittelbar nach denen des Materials vor der Wärmebehandlung.

Beispiel 1: Es sollen die mechanischen Eigenschaften einer in Sandform gegossenen 10% Aluminiumbronze mit einer gleichen Legierung verglichen werden, in welcher 3% des Aluminiumgehaltes durch Fe ersetzt sind. Die Kenntnis der Eigenschaften bei hoher Temperatur ist notwendig. Die erste Legierung, wir bezeichnen sie mit "A," hat die Typenformel Cu-Al, die zweite, "B" bezeichnet, hat die Typenformel Cu-Al-Fe. Aus dem Inhaltsverzeichnis (S. 359) finden wir, dass der Abschnitt, welcher die mechanischen Eigenschaften der Al-Bronzen enthält, auf S. 572 beginnt. Hier finden wir ein Inhaltsverzeichnis für diesen Abschnitt in welchem 15 Eigenschafts-Tafeln der Type Cu-Al und 6 Eigenschafts-Tafeln für die Type Cu-Al-Fe, vorhanden sind.

Wir wollen zuerst von der Legierung "A" (in *Sandform gegossen*) die Zugfestigkeit (*UTS*) in kg/mm^2, Prozent Dehnung (*El*) und die Brinell-Härtezahl (*BHN*) berücksichtigen. Aus den Tafeln finden wir:

t, °C / Tabelle	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	**46–53**		20		90–100		(13)
2	**49,9**		21,7				(3)
3	**29,1**	18,2	9,4	3,1			(2, 15)
4					76.7	<50	(12)
13	**42,2**		28,5		118		(26)
13	**52.0**		19.5		100		(7)

in cui sono contenuti, eccetto nel caso degli acciai, dove C è scritto per ultimo. (*N. B.* Un elemento ritenuto solo accidentale oppure giudicato come impurezza può in seguito trovarsi che ha un effetto importante sulle proprietà di una lega: vedi, ad es. il caso del silicio nel duralluminio.) Così Pb-Sb-Cu è la formula tipo delle leghe nelle quali la proporzione maggiore in peso è di Pb, quella intermedia è di Sb e quella minore è di Cu; mentre un acciaio al vanadio ha la formula Fe-V-C, sebbene C, in genere, è presente in proporzione maggiore di V. Le diverse leghe sono disposte in ordine alfabetico secondo le loro formule tipo.

Sotto una certa formula tipo le leghe sono disposte in ordine decrescente della proporzione del costituente principale quando questa è nota. Se questa non è nota esse sono disposte nell' ordine crescente del contenuto del secondo componente più abbondante. Sotto ogni composizione i dati sono disposti approssimativamente nell'ordine della complessità del trattamento. Così le proprietà dei getti (simbolo = G) vengono per prime, poi quelle del materiale lavorato a caldo, e infine quelle del materiale lavorato a freddo. Le proprietà del materiale trattato a caldo seguono subito dopo quelle del materiale prima del trattamento a caldo.

Esempio 1: Si desideri confrontare le proprietà meccaniche di un bronzo d'alluminio al 10% colato in sabbia, con quelle della stessa lega nella quale 3% di alluminio è stato sostituito con ferro, e precisamente si desideri conoscere le proprietà della lega a temperature elevate. La prima lega, che indicheremo con "A," ha la formula tipo Cu-Al; la seconda, che indicheremo con "B," ha la formula tipo Cu-Al-Fe. Se si consulta l'indice (p. 359) si trova che il capitolo contenente le proprietà meccaniche dei bronzi di alluminio comincia a p. 572. Qui si trova un indice in cui sono riportate 15 tabelle di proprietà per il tipo Cu-Al e 6 tabelle di proprietà per il tipo Cu-Al-Fe.

Consideriamo dapprima il carico di rottura (*UTS*) in kg/mm^2, l'allungamento per cento (*El*) e il numero di durezza Brinell (*BHN*) della lega "A" colata in sabbia (G_s). Dalle tabelle si trova:

t, °C / Tabe a	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	46–53		20		90–100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	—50	(12)
13	42,2		28,5		118		(26)
13	52,0		19,5		100		(7)

I valori della Tabella 1 rappresentano le proprietà medie della lega "A" e si accordano bene con quelli delle altre tabelle; si eccettuano solo i valori della Tabella 3, che probabilmente si riferiscono ad un materiale gettato in condizioni non soddisfacenti, cosa questa è facilmente possibile con i bronzi d'alluminio.

Se si considera le lega "B" allo stesso modo si ha:

t, °C / Tabella	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	300	
17	52,4		38,0		80		(10)
20	(7,6% Al, 2% Fe)				125	70	(12)

Sebbene si disponga di pochi dati, la lega "B" sembra sia resistente quanto la "A" e persino più duttile della "A" a 20°C, mentre la presenza del 2% di ferro ha accresciuto la durezza a 500°C. I numeri di durezza riportati nella (12) non si accordano però con quelli di altre fonti. In base alle tabelle tuttavia la lega "B" è un po' migliore.

Dall'indice (p. 370) si può sapere se nelle tabelle sono riportate leghe commerciali della composizione di "B." I numeri indici dei

the Finding Index. Turning to these numbers in the Finding Index, we find No. 45, "Alcumite:" Cu; Al, 7.5; Fe, 5.5; Ni, Mn, No. 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. If the alloys thus shown in the Finding Table are commercially available at the present time, reference to the firms producing them can no doubt be obtained from the advertising pages of metallurgical magazines or otherwise. It must, however, be borne in mind that other alloys, possibly of the type desired, are manufactured in various countries, without necessarily being known by a name which could be included in the Finding Index, while there are numerous manufacturers in every country having a well-developed metallurgical industry, who will be prepared to make up alloys to any desired specification, provided that patent rights do not interfere. In some instances, it may be noted that the properties of the materials as represented by data given in the corresponding table, can only be obtained by definitely stated methods of manufacture and treatment and these are, sometimes, available only at the hands of an individual manufacturing firm. Further, where alloys having trade names are given in the list, and if no definite data for these alloys as such are included, the inference that the alloy bearing the trade name will have the same properties as the alloy of similar composition listed in the detailed table, must be regarded as subject to the limitations just indicated.

Example 2: Given a Ni-Cr steel containing 3.5% Ni, 0.8% Cr and 0.25% C, to find the heat treatment giving the optimum combinations of tensile and notched-bar impact properties. From the Table of Contents, it is found that Ni-Cr steels are treated in the section beginning on p. 483. The first numbered table of this section is a table of compositions, in which No. 262 is found to correspond to the above composition. The table of contents at the beginning of the section (p. 483) shows that mechanical properties are given in Table 7, p. 510. Turning to this table, we locate alloy No. 262 (p. 511) and find that values of properties are given for 42 different conditions of this steel. Notched-bar impact test results are given under the following designations: IS_u (Izod machine using B. E. S. A. standard specimen), IS_v (Charpy machine using 45° V notch specimen), IS_x (Guillery machine, Mesnager notch). The energy absorbed in fracture is given in each case as there is no satisfactory basis for comparison of results as between the different types of specimen. The largest Izod values of No. 262 are for treatments h, j, k, and z, being respectively 8.85, 9.15, 9.0, and 9.0. Of these, "h" gives a material somewhat stronger and considerably more ductile than do the others. Meanings of symbols and abbreviations used in describing treatments are given in the table on p. 392. Treatment "h" reads as it stands "Same, Tp 650° Q_w." The "Same" refers to the previous treatment, *i.e.*, condition before tempering, which is N 820°. The whole treatment interpreted is: Normalized at 820° (*i.e.*, cooled in still air from 820°C), then tempered at 650°C and quenched in water. The other treatments which give high impact strengths, are: "1000° Q_o Tp 670°/120 Q_w" (*i.e.*, quenched in oil from 1000°C, tempered at 670° for 120 min, and quenched in water); "1000° Q_o Tp 650°/120 C_s 650° Q_w" (*i.e.*, quenched in oil from 1000°C, tempered at 650° for 120 min, cooled slowly, retempered at 650°C and quenched in water); and "850° Q_o Tp 675°/495 Q_w" (*i.e.*, quenched in oil from 850°C, tempered at 675° for 495 min, and quenched in water). These treatments give nearly as good properties, thus showing the necessity of a final water quench from 650–675°C. Consideration of some of the other treatments shows that cooling slowly from this temperature gives decidedly inferior notched-bar impact figures while not greatly affecting the tensile values. Quenching from lower temperatures gives better tensile properties, but inferior notched-bar impact figures. Inspection of values obtained on the other machines for these treatments and for others tables excepté celles de la Table 3, qui se rapportent probablement à un matériel fondu dans les conditions non satisfactoires, une circonstance qui est très possible avec le bronze d'aluminium.

Considérant l'alliage "B" de la même manière, nous avons:

t, °C / Table	UTS		El		BHN		Lit.
	20	500	20	500	20	300	
17	52,4		38,0		80		(10)
20	(7.6% Al, 2% Fe)				125	70	(12)

Quoiqu'il y ait peu de données disponibles, l'alliage "B" paraît être aussi résistant et plus ductible que "A" à 20°C, alors que la présence de 2 % de Fe a augmenté la dureté de l'alliage à 500°C. Les chiffres de dureté de (12) cependant, ne sont pas en accord avec ceux d'autres sources. On peut déduire sur la base des tables que l'alliage "B" est sensiblement le meilleur alliage.

L'index (p. 370) montre s'il y existe un alliage commercial de la composition de "B." Les nombres index des bronzes d'aluminium sont disposés en liste dans l'une des tables des alliages types qui se trouvent à la suite de l'index de recherche. En se reportant à ces nombres dans l'index de recherche, on trouve N° 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni; Mn, et N° 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. Si les alliages ainsi mentionnés dans la table de recherche sont disponibles dans le commerce actuellement, on trouvera sans doute les références des firmes qui les produisent dans les annonces des magazines métallurgiques ou autre part. Il ne faut pas oublier cependant que d'autres alliages, qui peuvent être du type désiré sont fabriqués dans des pays divers, sans être nécessairement connus par un nom qui pourrait se trouver dans l'index de recherche; il existe en effet de nombreux fabricants dans chaque pays possédant une industrie métallurgique bien développée qui peuvent fabriquer des alliages suivant les spécifications variées, à condition que les droits de patente ne s'y opposent pas. Dans certains cas, il faut remarquer que les propriétés des matières ainsi qu'elles sont représentées par les valeurs données dans les tables correspondantes, ne peuvent être obtenues que par des méthodes de fabrication et des traitements établis d'une façon définie, qui quelquefois ne sont réalisés que chez un seul fabricant. Lorsqu'il s'agit d'alliages portant des noms commerciaux mentionnés dans la liste, il n'a pas été indiqué de données définies pour ces alliages considérés comme tels, et, déduire que les alliages portant un nom commercial ont les mêmes propriétés que l'alliage de composition similaire mentionné dans la table détaillée, doit être regardé comme étant sujet aux limitations indiquées ci-dessus.

Exemple 2: Etant donné un acier au Ni-Cr contenant 3,5 % Ni, 0,8 % Cr et 0,25 % C, trouver le traitement thermique donnant la combinaison optimum relativement aux propriétés de traction et à l'essai de choc sur éprouvette entaillée. De la table des matières, on trouve que les aciers au Ni-Cr sont traités dans la section commençant à p. 483. La première table de cette section est une table de compositions, dans laquelle le N° 262 correspond à la composition donnée ci-dessus. La table des matières au commencement de la section (p. 483) montre que les propriétés mécaniques sont données dans la Table 7, p. 510; à cette table nous trouvons l'alliage N° 262 (p. 511) et constatons que les valeurs des propriétés sont données pour 42 différentes conditions de cet acier. Les résultats concernant l'essai de choc sur éprouvette entaillée sont donnés sous les désignations suivantes: IS_u (Machine d'Izod, utilisant des éprouvettes types B. E. S. A.), IS_v (Machine de Charpy utilisant une éprouvette avec entaille 45°V), IS_x (Machine de Guillery, éprouvette avec entaille Mesnager). L'énergie absorbée dans la rupture est donnée dans chaque cas, car il n'existe pas de base convenable pour la comparaison des résultats entre les différents types d'éprouvettes. Les valeurs Izod les plus fortes concernant le N° 262 sont obtenues avec les traitements

Der Wert in der Tabelle 1 stellt die Durchschnittseigenschaften der Legierung "A" dar, und stimmt ziemlich gut mit jenen in den anderen Tabellen überein. Ausgenommen jedoch die Werte der Tabelle 3, welche wahrscheinlich für ein Material gelten, das unter nicht befriedigenden Bedingungen gegossen worden ist. Bei Aluminiumbronzen ist ein solcher Fall sehr möglich. Nehmen wir die Legierung "B," so hat man in gleicher Weise:

Tabelle \ t, °C	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
17	52,4		38,0		80		([10])
20	(7.6% Al, 2% Fe)				125	70	([12])

Obgleich weniger Daten vorliegen, scheint die Legierung "B" bezüglich der Zugfestigkeit ebenso gut wie "A," bezüglich der Duktilität bei 20° besser zu sein, während die Anwesenheit von 2% Fe die Härte bei 500°C erhöht. Die Härtezahlen von ([12]) aber stimmen mit denen aus anderen Quellen stammenden nicht überein. Auf Grund der Tafeln ist "B" eine etwas bessere Legierung als "A."

Der Index (S. 370) zeigt an, ob irgend eine Handelslegierung von der "B" Zusammensetzung gegeben ist. Die Indexzahlen der Aluminiumbronzen sind in einer der Tafeln für Legierungstypen eingetragen, die dem Nachschlage-Index folgen. Sehen wir diese Zahlen im Nachschlage-Index nach, so finden wir No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni, Mn; No. 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. Sind diese Legierungen gegenwärtig handelsüblich, so kann vermutlich die Erzeugerfirma in dem Inseratenteil der Fachzeitschriften und auch sonst, gefunden werden. Es muss jedoch berücksichtigt werden, dass andere Legierungen, möglicherweise gerade von der gewünschten Type, in den verschiedenen Ländern erzeugt werden können, die vielleicht keinen Namen tragen, der in dem Nachschlage-Index angegeben werden konnte. Es gibt in jedem Lande mit einer gut entwickelten Metallindustrie, eine Anzahl von Fabriken die imstande sind, soweit nicht Patentrechte vorliegen, jede Legierung von besonderer Zusammensetzung herzustellen.

Es möge noch bemerkt werden, dass in mancher Beziehung, die in den entsprechenden Tabellen angegebenen Eigenschaften nur durch bestimmte Fabrikations-Methoden und Behandlungen erreicht werden können, die zuweilen nur den einzelnen Erzeugerfirmen zur Verfügung stehen. Ferner, wo in den Tabellen Legierungen mit Handelsmarken angegeben sind und keine definitive Werte für solche in den Tafeln angeführt sind, ist eine Schlussfolgerung, wie aus dem Vorhergegangenen folgt, dass eine Legierung mit Handelsmarke dieselben Eigenschaften habe als eine ähnlich zusammengesetzte Legierung die sich in der Tabelle vorfindet, sehr einzuschränken.

Beispiel 2: Gegeben ist ein Ni-Cr-Stahl mit 3,5% Ni, 0,8% Cr, und 0,25% C. Es ist die Wärmebehandlung zu finden, die ein Optimum an Zugfestigkeit und Schlagfestigkeit an einem gekerbten Probestück gibt. Aus dem Inhaltsverzeichnis findet man, dass Ni-Cr-Stähle in dem S. 483 beginnenden Abschnitt behandelt werden. Die erste Zahlentafel dieses Abschnittes gibt die Zusammensetzungen an worunter No. 262, der angegebenen Zusammensetzung entspricht. Das Inhaltsverzeichnis zu Beginn des Abschnittes (S. 483) gibt an, dass die mechanischen Eigenschaften in der Tafel 7, S. 510, zu finden sind. Hier findet man die Legierung No. 262 (S. 511) und sieht, dass die Eigenschaften für 42 verschiedene Behandlungen für diese Stahlsorte vorliegen. Die Schlagfestigkeit (Kerbeneinschnitt) ist unter der folgenden Bezeichnung angegeben: IS_u (Izod Machine, B. E. S. A. standard Probe), IS_v (Charpy-Machine, mit 45° V-Kerbe), IS_x (Guillery Machine, Kerbenformstück nach Mesnager). *Die beim Bruch absorbierte Energie* ist in jedem Falle angegeben, da keine befriedi-

bronzi di alluminio sono elencati in una delle tabelle dei tipi di leghe che seguono l'indice. Andando a cercare questi numeri nell'indice, si trova No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni; Mn; e No. 141, "Ampco Bronze:" Cu; Al, 7–11; Fe, 1–5. Se le leghe così indicate si trovano in commercio, si può sapere il nome delle ditte che le producono dalla réclame delle riviste metallurgiche o in qualche altro modo. Può darsi però che nei diversi paesi vengano fabbricate altre leghe, e che esse non siano conosciute con un nome che potrebbe essere incluso nell'indice. In ogni nazione con una industria metallurgica bene sviluppata, vi è un gran numero di produttori i quali sono in grado di fabbricare leghe con qualsiasi requisito purchè non esistano diritti di brevetti. Deve ancora osservarsi che le proprietà, quali sono rappresentate dai valori contenuti nelle tabelle, in alcuni casi possono solo ottenersi con processi di fabbricazione e trattamento ben definiti, e che questi talvolta sono a conoscenza esclusiva di una singola ditta fabbricante. Inoltre, quando nell'elenco sono contenute leghe con nomi commerciali, nessun valore definito è riportato per esse, e la deduzione che la lega con quel certo nome avrà le stesse proprietà di quella di composizione simile elencata nella tabella deve considerarsi sottoposta alle limitazioni sopraindicate.

Esempio 2: Dato un acciaio al Ni-Cr contenente 3,5% Ni, 0,8% Cr e 0,25% C, trovare qual'è il trattamento termico che dà l'optimum di carico di rottura e di resilienza. Nell'indice si trova che gli acciai al Ni-Cr sono trattati nel capitolo che comincia a p. 483. La prima tabella di questo dà le composizioni, e in essa si trova che il numero 262 corrisponde alla composizione di sopra. Dall'indice all'inizio del capitolo (p. 483) si ricava che le proprietà meccaniche sono esposte nella Tabella 7 (p. 510). Consultando questa si vede che a p. 511 sono riportati valori delle proprietà per 42 condizioni differenti dell'acciaio No. 262. I risultati delle prove di resilienza sono riportati sotto le seguenti designazioni: IS_u (macchina Izod con provino B.E.S.A.), IS_v (macchina Charpy con provino munito di intaglio V a 45°), IS_x (macchina Guillery con barretta Mesnager). L'energia assorbita nella rottura è data per ogni caso, giacchè non vi son elementi sufficienti per confrontare i risultati ottenuti con i diversi tipi di prove. I più grandi valori Izod del numero 262 sono per i trattamenti h, j, k, e z, e sono rispettivamente 8,85; 9,15; 9,0 e 9,0. Fra essi, "h" dà un materiale un po' più resistente e notevolmente più duttile che gli altri. I significati dei simboli e le abbreviazioni adoperate nel descrivere i trattamenti sono indicati nella tabella a p. 392. Il trattamento "h" è indicato con "Same, Tp 650° Q_w." Il "Same" (lo stesso) si riferisce al trattamento precedente, e cioè alla condizione prima del rinvenimento, che è N 820°. L'intero trattamento perciò è normalizzato a 820° (e cioè raffreddato in aria calma a partire da 820°C), quindi rinvenuto a 650° e temprato in acqua. Gli altri trattamenti che danno resilienza elevata sono "1000° Q_o Tp 670°/120 Q_w" (e cioè temprato in olio a partire da 1000°C, rinvenuto a 670° per 120 min, e temprato in acqua; "1000° Q_o Tp 650°/120 C_s 650° Q_w" (cioè temprato in olio a partire da 1000°C, rinvenuto a 650° per 120 min, raffreddato lentamente, rinvenuto di nuovo a 650°C e temprato in acqua; e "850° Q_o Tp 675°/495 Q_w" (cioè temprato in olio a partire da 850°C, rinvenuto a 675° per 495 min, e temprato in acqua). Questi trattamenti danno tutti quasi le stesse buone proprietà e mostrano così la necessità di una tempra finale in acqua a partire da 650–675°C. Se si considerano alcuni altri trattamenti, si vede che il raffreddamento lento a partire da questa temperatura dà valori di resilienza decisamente inferiori, anche se non influenza molto i valori del carico di rottura. La tempra a partire da temperature più basse dà proprietà tensorie migliori, ma valori di resilienza più bassi. L'esame dei valori ottenuti per questi trattamenti e per altri per i quali non sono dati valori Izod, mostra che il trattamento "h" dà l'optimum dei valori desiderati.

for which no Izod values are given, show that treatment "h" gives the optimum desired values.

II. Name of Alloy Is Known, Its Composition and Properties Are Desired

Refer to the Finding Index, p. 370. The first column of this index contains the Index Numbers by which commercial alloys are identified when their properties occur in the tables. The second column contains 1510 trade names of alloys included in the following classes:

(*a*) Trade mark names of patented alloys, as "Alpax."

(*b*) Trade mark names of alloys no longer protected by patent (*cf.* Duralumin in France, where name "Aldal" is used for an alloy of approximately the same composition, the name Duralumin being protected).

(*c*) Names of inventor or manufacturer given to alloys, the names or compositions not necessarily being protected, as Babbitt metal.

(*d*) Names generally applied to certain types of alloys, as Cartridge Brass.

(*e*) Names of types of alloys including a wide range of compositions, as Chrome Nickel steel. In this case, particular alloys of this type may be found from Tables of Alloy Classes, p. 388.

(*f*) Designations of standard or tentative standard alloys, and certain government-specification alloys. These will be found under the alloy type as: Brass ingots, A. S. T. M. Spec. B30–22 or Government Bronze, Spec. G.

No distinction is made in the Finding Index among the first four classes, except that in some cases it has been necessary to identify an alloy, known usually by a number, by adding the manufacturer's name, as in the case of alloy No. 193 of the Driver Harris Co. This is listed under Ferronickel, but cross-reference is given to this and similar alloys under "Numbered Alloys." In other cases the manufacturer is not mentioned.

In class (*d*) no attempt has been made to include all alloys to which usage has given a name, as Spring Steel, Dynamo Sheets, etc., although such alloys are useful for the purpose indicated.

With regard to class (*f*) it should be mentioned that specifications may be drawn up regardless of existing patents and, of course, in ignorance of pending ones.

The names of alloys are arranged alphabetically regardless of type, excepting in the case of: (1) Alloys known by a manufacturer's number. (2) Specification alloys known by number or letter. (3) Alloys, the first part of whose name is descriptive of condition (*e.g.*, hard solder), where there are several such included in one type. Such alloys are listed under the name of the type and where commonly used, cross-references are also given under first part of name.

The third column of the Finding Index gives the compositions of the alloys. In stating the composition, the elements together with their weights % are given in descending order of amounts in the alloy. Where the % of the first, *i.e.*, largest constituent, is not given, it has not been determined by analysis. Where the amounts of the last constituents are not given, they are only incidental or impurities. Where no percentages are given, the information has not been available.

Where the composition of an alloy varies over a range of values, the limits have been stated, as Index No. 915, MS steel: Fe; Cr, 0.8–1.1; Mo, 0.3–0.4; Mn, 0.6–0.9; C, 0.4–0.6.

The fourth column of the Finding Index contains the page numbers where values of properties of the alloy may be found; the page numbers where the values of properties of a similar alloy may be found are indicated by italic type.

The electrical, magnetic and optical properties of metals and alloys will be found in a succeeding volume of I. C. T.; no page reference to such data can therefore be given in the Finding Index.

h, j, k et z, et sont respectivement 8,85, 9,15, 9,0 et 9,0. Parmi ceux-ci, "h" donne une matière un peu plus résistante et considérablement plus ductile que les autres. La signification des symboles et les abréviations utilisées pour spécifier les traitements sont données dans la table à la p. 392. Le traitement "h" représente "Same, Tp 650° Q_w," "Same" (c'est-à-dire le même) se rapporte au traitement antérieur, c'est-à-dire, à la condition avant le revenu, qui est N 820°. L'interprétation de tout le traitement est la suivante: Normalisé à 820° (c'est à dire refroidi dans l'air calme à partir de 820°C), ensuite revenu à 650° puis trempé à l'eau. Les autres traitements qui donnent une grande résistance au choc sont: "1000° Q_o Tp 670°/120 Q_w" (c'est à dire, trempé à l'huile à partir de 1000°C, revenu à 670° pendant 120 minutes, refroidi doucement, de nouveau revenu à 650°C et trempé à l'eau); et "850° Q_o Tp 675°/495 Q_w" (c'est-à-dire trempé à l'huile à partir de 850°C, revenu à 675°C pendant 495 min. et trempé à l'eau). Ces traitements donnent tous à peu près d'aussi bonnes propriétés montrant ainsi la nécessité d'une trempe à l'eau finale à partir de 650–675°C. L'examen de quelques autres traitements montre que le refroidissement lent à partir de cette température donne décidément des chiffres inférieurs à l'essai de choc sur éprouvette entaillée tout en n'affectant pas beaucoup les valeurs de traction. Une trempe à partir de températures plus basses donne des meilleures propriétés à la traction, mais des chiffres inférieurs à l'essai de choc sur éprouvette entaillée. L'examen des valeurs obtenues sur les autres machines pour ces traitements et pour d'autres pour lesquels il n'a pas été donné de valeurs Izod montre que le traitement "h" donne l'optimum désiré.

II. Le nom de l'alliage est connu; on désire connaître sa composition et ses propriétés

Consulter l'index de recherche, p. 370. La première colonne de cet index contient les nombres index au moyen desquels les alliages commerciaux sont identifiés lorsque leurs propriétés sont mentionnées dans les tables. La deuxième colonne contient 1510 noms commerciaux des alliages compris dans les classes suivantes:

(*a*) Noms commerciaux d'alliages brevetés, comme "Alpax."

(*b*) Noms commerciaux d'alliages dont le brevet est expiré; (par exemple: Duralumin en France, où le nom "Aldal" est utilisé pour un alliage ayant approximativement la même composition, le nom Duralumin étant déposé).

(*c*) Noms de l'inventeur ou du fabricant donnés aux alliages, les noms ou les compositions n'étant pas nécessairement déposés, comme métal "Babbitt."

(*d*) Noms généralement employés pour désigner certains types d'alliages, comme "Cartridge brass," laiton pour cartouches.

(*e*) Noms de types d'alliages comportant un large intervalle de composition, comme acier en chrome nickel. Dans ce cas on peut trouver des alliages particuliers de ce type dans les "Tables of Alloy Classes," p. 388.

(*f*) Désignation d'alliages standards ou alliages standards tentatifs et certains alliages suivant spécifications gouvernementales. Ceux-ci seront trouvés sous le type d'alliage comme par exemple: Brass ingots (laiton en lingots), A. S. T. M. Spec. B30–22 ou Bronze du Gouvernement, Spec. G.

Il n'a pas été fait de distinction dans l'index de recherche pour les quatre premières classes, excepté dans quelques cas où il a été nécessaire pour identifier un alliage connu ordinairement par un nombre, d'ajouter le nom du fabricant comme dans le cas de l'alliage N° 193 de la Driver Harris Co. Celui-ci est inscrit sous ferronickel, mais il y a une référence pour cet alliage et pour les alliages similaires sous "Numbered Alloys." Dans d'autres cas le fabricant n'est pas mentionné.

Dans la classe (*d*) on n'a pas cherché à inclure tous les alliages auxquels l'usage a donné un nom, tels que acier à ressorts, tôles

gende Basis zum Vergleich der Ergebnisse bei verschiedenen Typen der Proben vorhanden sind. Der höchste Izod-Wert für No. 262 ergibt sich für die Behandlung h, j, k und z, und beträgt der Reihe nach 8,85, 9,15, 9,0 und 9,0. Von diesen gibt "h" ein Material höherer Zugfestigkeit und ein deutlich duktileres Material als die anderen. Erklärungen der Zeichen und die Behandlung betreffenden Abkürzungen sind in der Tabelle S. 392 angegeben. Die Behandlung "h" ist durch "Same, Tp 650° Q_w" in den Tafeln ausgedrückt. "Same" zeigt vorhergegangene Behandlung an, d. h. Zustand vor der Anlassung, welche "N 820°" ist. Die ganze Behandlung ist angezeigt: Normalisiert bei 820° (d. h. gekühlt in ruhender Luft von 820° herunter), dann bei 650°C angelassen und in Wasser abgeschreckt. Die anderen Behandlungen, welche eine sehr grosse Schlagfestigkeit geben, sind: 1000° Q_o Tp 670°/120 Q_w (d. h. bei 1000° in Öl abgeschreckt bei 670°, 120 Minuten lang angelassen und in Wasser abgeschreckt); "1000° Q_o Tp 650°/120 C_s 650° Q_w" (bei 1000° in Öl abgeschreckt, für 120 Minuten lang bei 650° angelassen, langsam gekühlt, nochmals bei 650° angelassen und in Wasser abgeschreckt); ferner "850° Q_o Tp 675°/495 Q_w" (d. h. bei 850° in Öl abgeschreckt, 495 Minuten lang bei 675° angelassen, und in Wasser abgeschreckt). Diese Behandlungen geben ungefähr gleich gute Eigenschaften und zeigen die Notwendigkeit einer am Schlusse vorgenommen Wasserabschreckung von 650–675°. Die Betrachtung einiger anderer Behandlungen zeigt, dass eine langsame Kühlung von dieser Temperatur herunter entschieden niedrigere Werte für die Schlagfestigkeit gibt, während die Zugfestigkeit und Duktilität nicht stark beeinflusst wird. Abschreckung bei tieferen Temperaturen gibt bessere Zugfestigkeit und Duktilität, aber niedrigere Werte für die Schlagfestigkeit. Eine Durchsicht der Werte die mit anderen Maschinen erhalten werden, zeigt für diese Behandlungen und andere, für welche keine Izod-Werte gegeben sind, dass die "h" Behandlung das Optimum der gewünschten Eigenschaft gibt.

II. Der Name der Legierung ist bekannt, es sind ihre Zusammensetzung und Eigenschaften zu ermitteln

Siehe im Nachschlage-Index S. 370 nach. Die erste Kolonne in diesem enthält die Index-Zahl, durch welche Handelslegierungen bezeichnet sind, wenn ihre Eigenschaften in den Tabellen vorkommen. Die zweite Kolonne enthält 1510 Handelsnamen von Legierungen die in folgende Klassen eingeteilt sind.

(*a*) Handelsmarken patentierter Legierungen, wie z. B. "Alpax."

(*b*) Handelsmarken von Legierungen, nicht mehr unter Patentschutz stehend (*vgl.* Duralumin in Frankreich, wo der Name "Aldal" für eine Legierung von ungefähr derselben Zusammensetzung benützt wird, da der Name Duralumin geschützt ist).

(*c*) Die Legierung trägt den Namen des Erfinders oder des Erzeugers. Der Name selbst braucht nicht notwendig geschützt zu sein; z. B. Babbitt-Metall.

(*d*) Namen die im allgemeinen gewissen Legierungstypen gegeben werden; z. B. "Cartridge brass," Patronen-Messing.

(*e*) Namen von Legierungen deren Zusammensetzung in weitem Ausmasse varieren kann, z. B. Chrom-Nickel Stahl. In solchem Fall, die besondere Legierung dieser Type in "Tables of Alloy Classes," S. 388 zu finden ist.

(*f*) Als Standards bestimmte Legierungen oder solche als Prüfungs-Standard geltende, ferner gewisse staatlich vorgeschriebene Legierungen. Diese werden unter folgenden Legierungstypen gefunden: Brass ingots, A. S. T. M. Spec. B30–22 Government Bronze, Spec. G.

Es ist in den ersten vier Klassen kein Unterschied im Nachschlage-Index gemacht, ausgenommen, dass es in manchen Fällen notwendig war eine, sonst nur durch eine Zahl bekannte Legierung durch Hinzufügung des Namens des Fabrikants näher zu bezeichnen, z. B. bei der Legierung No. 193 der Driver

II. Si suppone noto il nome della lega e si desidera conoscerne la composizione e le proprieta

Si consulti l'indice di ricerca a pag. 370. La prima colonna contiene i numeri indici con cui sono indicate le leghe commerciali, e la seconda 1510 nomi commerciali di leghe suddivisi nelle classi seguenti:

(*a*) Nomi commerciali di leghe brevettate, come "Alpax."

(*b*) Nomi commerciali di leghe non più protette da brevetti (ad es. in Francia si usa il nome "Aldal" per una lega che ha approssimativamente la stessa composizione del duralluminio, essendo il nome duralluminio protetto da brevetto).

(*c*) Nomi di inventori o fabbricanti dati alle leghe. I nomi o le composizioni non sempre sono protette da brevetti, come ad es. nel caso del metallo "Babbitt."

(*d*) Nomi generalmente applicati a certi tipi di leghe, come ad es. "Cartridge brass," ottone per cartucce.

(*e*) Nomi di tipi di leghe che possono avere composizioni oscillanti entro limiti larghi, come ad es. acciai al cromo-nichel. In questi casi, si possono trovare leghe particolari di detto tipo nelle "Tables of Alloy Classes," p. 388.

(*f*) Indicazioni di leghe standard, o tentativi standard, e di certe leghe con le caratteristiche richieste da amministrazioni governative. Queste si troveranno riportate sotto i tipi di leghe come: Brass ingots (lingotti di ottone), A. S. T. M. Spec. B30–22, oppure bronzo secondo le prescrizioni governative, Spec. 9.

Nessuna distinzione è fatta nell'indice tra le prime quattro classi eccetto che in alcuni casi è stato necessario aggiungere, al numero che ordinariamente contradistingue una lega, il nome del fabbricante, come nel caso della lega N° 193 della Driver Harris Co. Questa è elencata tra i ferro-nichel, ma sotto "Numbered Alloys" vi è un rapporto a questa ed a leghe simili al N°. 193. In altri caso non è fatta menzione del fabbricante.

Nella classe (*d*) non si è tentato di comprendervi tutte le leghe alle quali l'uso ha dato un nome, come acciaio per molle, lamierini per dinamo, ecc., sebbene dette leghe siano utili per gli scopi indicati.

Riguardo alla classe (*f*) deve ricordarsi che determinate caratteristiche possono ottenerdi indipendentemente dal brevetti esistenti e, naturalmente, nell'ignoranza di eventuali in corso.

I nomi delle leghe sono disposti per ordine alfabetico senza tener conto del loro tipo tranne il caso di: (1) Leghe indicate con il numero di un fabbricante. (2) Leghe speciali note con un numero o una lettera. (3) Leghe di cui la prima parte del nome ne descrive la natura (per es. "hard solder," saldatura forte) quando ve ne sono parecchie comprese in uno stesso tipo. Tali leghe sono elencate sotto il nome del tipo, e, quando esse sono comunemente adoperate, si trovano riportate indicazioni anche sotto la prima parte del nome.

La terza colonna dell'indice dà le composizioni delle leghe. Nell'indicare la composizione, gli elementi e le rispettive percentuali sono date in ordine decrescente del contenuto nella lega. Quando il percento del primo costituente, e cioè quello più abbondante, non è indicato, significa che esso non è stato determinato con l'analisi. Quando le proporzioni degli ultimi componenti non sono indicate, essi sono soltanto costituenti accidentali o impurezze. Se le percentuali non sono riportate, significa che non si è potuto avere l'informazione relativa.

Quando la composizione di una lega può assumere tutta una serie di valori, sono stati indicati i limiti entro i quali i valori possono oscillare, come per es. per Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0, 4; Mn, 0,6–0,9; C, 0,4–0,6.

Nella quarta colonna dell'indice sono indicate le pagine dove si possono trovare valori delle proprietà della lega (in caratteri romani) oppure dove si possono trovare i valori delle proprietà di una lega simile (in corsivo).

No data on resistance to corrosion are included in these tables. In the opinion of the most competent experts on the subject, it is not possible to give quantitative data for the corrosion resistance of metals and alloys. No page references can therefore be given in regard even to certain alloys which are chiefly valued on account of their resistance to corrosion. These, however, are listed in the tables of alloy types.

The sources of information for the Finding Index have been as follows: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; names and compositions given by the co-operating experts; and current metallurgical and technological literature.

III. It Is Desired to Find an Alloy Having Certain Desired Properties

For this purpose consult the Table of Properties on p. 610, directions being given there.

de dynamo, etc., quoique de tels alliages soient utiles pour le but indiqué.

En ce qui concerne la classe (*f*), il faut mentionner que des spécifications peuvent être rédigées sans tenir compte des patentes existantes et naturellement aussi dans l'ignorance des brevets demandés.

Les noms des alliages sont disposés dans l'ordre alphabétique sans tenir compte de leur type, excepté dans les cas suivants: (1) Alliages connus par un numéro de fabrique. (2) Certains alliages connus par un nombre ou une lettre. (3) Alliages dont la première partie de leurs noms est descriptive de la condition (par ex. "hard solder," soudure dure) et où il existe plusieurs variétés incluses dans un type. De tels alliages sont inscrits sous le nom du type et lorsqu'ils sont d'un usage commun, sont aussi mentionnés dans l'index par la première partie de leur nom.

La troisième colonne de l'index de recherche donne les compositions des alliages. En établissant la composition, on a inscrit les éléments avec leurs poids en % successivement dans l'ordre des proportions décroissantes dans l'alliage. Lorsque le pourcent du premier, c'est-à-dire le constituant principal, n'est pas donné, c'est qu'il n'a pas été déterminé par l'analyse. Lorsque les proportions des derniers constituants ne sont pas mentionnés, ceux-ci ne sont qu'accessoires ou bien sont des impuretés. Lorsqu'aucun pourcentage n'est donné, c'est que l'information n'a pas été disponible.

Lorsque la composition d'un alliage varie suivant un intervalle de valeurs, les limites ont été fixées: par ex. Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0,4; Mn, 0,6–0,9; C, 0,4–0,6.

La quatrième colonne de l'index de recherche contient en caractères romains les numéros des pages où l'on peut trouver les propriétés de l'alliage, ou en italique les numéros des pages, où l'on peut trouver les valeurs des propriétés d'un alliage similaire.

On trouvera les propriétés électriques, magnétiques et optiques des métaux et alliages dans un volume suivant des T. C. I.; on ne peut donc donner aucune page de référence pour de telles données dans l'index de recherche.

On ne trouvera dans ces tables aucune donnée relative à la résistance à la corrosion. D'après l'opinion des experts les plus compétents sur ce sujet, il n'est pas possible de donner des valeurs quantitatives pour la résistance à la corrosion des métaux et alliages. On ne peut donc donner aucune référence en ce qui concerne même certains alliages dont la valeur est surtout due à leur résistance à la corrosion. Ceux-ci, cependant sont mentionnés dans les tables des types d'alliages.

Les sources d'information pour l'index de recherche ont été les suivantes: List of Names of Alloys établie par William Campbell préparée pour le Comité B-2 de l'A. S. T. M.; noms et compositions données par les experts coopérants; et la littérature métallurgique et technologique courante.

III. On désire trouver un alliage ayant certaines propriétés désirées

Pour cela, consulter la Table des Propriétés à la p. 610, où les instructions sont données.

Harris Co. Sie ist unter Ferronickel mit einem entsprechenden Hinweis angeführt, der dieser und ähnlichen Legierungen unter "Numbered Alloys" beigefügt wird.

Zu (*d*). Es ist nicht die Absicht gewesen, alle solche Legierungen hier zu vereinigen denen der Gebrauch besondere Namen, wie Feder-Stahl, Dynamo-Lamellen, u. s. w., beigelegt hat, obgleich diese Legierungen für die angezeigte Verwendung nützlich sind.

Hinsichtlich (*f*) wäre zu bemerken, dass die Vorschriften ohne Rücksicht auf vorhandene und in Unkenntnis angemeldeter Patente, niedergeschrieben werden können.

Die Namen der Legierungen sind in alphabetischer Reihenfolge ohne Rücksicht auf die Type angeordnet. Ausgenommen: (1) Die Legierung hat die Nummer eines Erzeugers. (2) Besondere Legierungen die durch eine Zahl oder Buchstaben kenntlich gemacht sind. (3) Legierungen in deren Namen der erste Teil ihre Natur beschreibt (z. B. "hard solder," hart Lot). Es sind dann mehrere in einer Type vereinigt. Solche Legierungen sind unter dem Namen der Type angeführt unter welcher sie gewöhnlich gebraucht werden. Unter dem ersten Teil der Namen sind Hinweisdaten gegeben.

Die dritte Kolonne des Nachschlage-Index enthält die Zusammensetzung der Legierungen. Die Elemente, welche die Zusammensetzung ausdrücken sind zusammen mit ihrem Prozentgehalt absteigend nach diesem, angeordnet. Ist der Prozentgehalt des Hauptbestandteiles nicht angegeben, so ist er analytisch nicht bestimmt. Sind die Mengen des letzten Bestandteiles nicht angegeben, so ist dieser nur zufällig vorhanden oder nur Verunreinigung. Fehlen der Prozentzahlen bedeutet, dass keine diesbezügliche Angaben erreichbar waren.

Ändert sich die Zusammensetzung einer Legierung innerhalb einer Grenze, so werden nur die Grenzwerte angegeben, z. B. Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0,4; Mn, 0,6–0,9; C, 0,4–0,6.

Die vierte Kolonne des Nachschlage-Index enthält die Seitenzahlen, wo die Werte für die Eigenschaften gefunden werden können. Die Eigenschaften ähnlicher Legierungen sind auf den kursiv gedruckten Seitenzahlen zu finden.

Die elektrischen, magnetischen und optischen Eigenschaften der Metalle und Legierungen sind Gegenstand späterer Bände der I. C. T. Aus diesem Grunde sind keine diesbezügliche Hinweise im Nachschlage-Index angegeben.

In den Tafeln finden sich keine Angaben über Korrosion. Nach der Meinung massgebender Fachleute ist es nicht möglich quantitative Angaben über den Widerstand gegen Korrosion zu machen. Es sind daher diesbezüglich keine Angaben vorhanden, selbst in Hinblick auf gewisse Legierungen die gerade wegen ihres Widerstandes gegen Korrosion besonders geschätzt werden. Sie sind aber unter den Legierungstypen zu finden.

Für den Nachschlage-Index sind folgende Quellen massgebend gewesen: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; Namen und Zusammensetzung wie sie von den Mitarbeitern (Experten) angegeben worden sind; die vorhandene metallurgische und technologische Literatur.

III. Es ist eine Legierung mit gewünschten Eigenschaften aufzufinden

Zu diesem Zwecke benütze man die S. 610 vorhandenen Eigenschaftstafeln, wo weitere Richtlinien gegeben sind.

Le proprietà elettriche, magnetiche e ottiche dei metalli e delle leghe si troveranno in un volume successivo delle I. C. T.; non è possibile perciò fare richiami a questi valori nell'indice.

Dati sulla resistenza alla corrosione non sono inclusi nelle tabelle, giacchè, secondo i maggiori conoscitori dell'argomento, non è possibile indicare con dati quantitativi la resistenza alla corrosione. Valori numerici non sono perciò riportati neppure per certe leghe che sono sopratutto apprezzate per la loro resistenza alla corrosione. Esse tuttavia sono elencate nelle tabelle dei tipi di leghe.

Le fonti per la compilazione dell'indice sono state: William Campbell's List of Names of Alloys, preparato per il Comitato B-2 della A. S. T. M.; nomi e composizioni fornite dai collaboratori; la letteratura tecnologica e metallurgica corrente.

III. Si desideri trovare una lega che abbia certe proprietà

A questo scopo si consulti la tabella delle proprietà a p. 610 dove si troveranno indicazioni in proposito.

FINDING INDEX OF ALLOYS

Index No.	Name	Composition	Page
1	A alloy (forging)	Al, 77; Zn, 20; Cu, 3	538, 608
2	Abyssinian gold	Cu, 88; Zn, 11.5; Au, 0.5 (*v. also* Index No. 1371)	
3	Accumulator metal	Pb, 90; Sn, 9.2; Sb, 0.8	467, 557
4	Acid bessemer pig	Fe; C, 3.5–4; Si, 1–1.5; Mn, 0.5; P, ≯ 0.1; S, ≯ 0.05	
5	Acid bronze	Cu, 88–82; Sn, 8–10; Pb, 2–8; Zn, 2–0; P, 0–0.2	561, 562, 567
6	Acid bronze	Cu, 74; Pb, 17; Sn, 8; Zn, 1.5	561, 562
	Acid resisting alloys:	For list, *v.* p. 391	
7		Pb, 52; Sn, 35; Sb, 8; Cu, 5	557
8		Cu, 83; Sn, 11; Zn, 6; Pb*	569
9	U. S. patent 1 333 706	Cr, 60; Fe, 39; C, 0.3–0.8	
10	U. S. patent 1 375 081	Fe, 56; Cr, 40; Mo, 4; C, 1.5	
11	Can. patent 206 645	Ni, 46–38; Cu, 31–38; Fe, 16–20; Cr, 7–5; Mn, 0.3–0.8	
12	Acid resisting steel (U. S. patent 1 391 450)	Fe, 86; Cr, 13; C, 0.3; Mn; Si; P; S	471, 472, 508, 603
13	Acieral (cast)	Al; Cu, 6; Ni, 1; Si, 0.4; Fe; Mg; Zn	
14	Acieral (sheet)	Al; Cu, 2.3–3.8; Mn, 1–1.5; Fe, 0.7–1.4; Mg	534
15	Acme nickel steel	Fe; Ni, 30.5; Cr, 1.4–1.6; C, 0.3; Mn; Si; P; S	
16	Admiralty, A (Admiralty condenser tube, Admiralty metal)	Cu, 70; Zn, 29; Sn, 1	469, 556, 600
17	Admiralty brass	Cu, 62; Zn, 37; Sn, 1.4	470, 556
18	Admiralty gun metal (Admiralty bronze)	Cu, 88; Sn, 10; Zn, 2	476, 565
19	Admiralty gun metal†	Cu, 88–86; Sn, 10; Zn, 1.1–1.5; Pb, 0.2–1.7; As, 0.5; Fe, 0.06–0.08	566, 567, 570–572
20	Admiralty white metal	Sn; Sb, 8–9; Cu, 2–7	476, 557
21	Adnic (Admiralty nickel)	Cu, 70; Ni, 29; Sn, 1	601
22	Advance	Cu, 54–55; Ni, 44–46; Mn, 0.8–1.2; Fe, 0.5	480, 601, 606
23	Aerolite	Al, 97; Cu, 1.2; Fe, 1; Si, 0.5; Mg, 0.4; Zn	533
24	Aerolite pistons	Al, 86; Cu, 12; Mn, 2	467, 534
25	Aero metal (cast)	Al, 67; Zn, 28; Cu, 4.2; Fe, 0.5; Si, 0.5	537
26	Aero metal (sheet)	Al, 96; Mg, 2.1–2.9; Cu, 0.2–0.6; Fe; Mn; Si	464, 542
27	Aeromin	Al; Mg, 6.2; Fe, 0.8; Si, 0.3	542, 608
28	Aeron (Scleron II)	Al; etc., *v.* Scleron	
29	Agrilite (No. 5)	Cu, 70.5; Pb, 24; Sn, 5.4; Ni, 0.1; P, 0.005	561, 562, 567
30	Aich metal	Cu, 60; Zn, 38; Fe, 1.5	556
31	Air hardening steel (Key No. 267, p. 512)	Fe; Ni, 3.7–4.3; Cr, 1.4–1.6; Mn, 0.4; C, 0.3; Si; P; S	512, 513, 604
32	Ajax metal	Fe, 70–30; Ni, 25–50; Cu, 5–20	
33	Ajax phosphor bronze	Cu, 79; Sn, 10; Pb, 10; P, 0.7	562
34	Ajax plastic bronze	Cu, 64; Pb, 30; Sn, 5; Ni, 1	562
35	Ajax plastic bronze	Cu: Sn ≮ 91:9; Pb, ≮20 (U. S. reissue patent 12 880)	561, 562, 567
36	Akrit	Co, 38; Cr, 30; W, 16; Ni, 10; Mo, 4; C, 2–5	593
37	Aladar	Name used in France for Alpax	
38	Alargan	Ag; Al	
39	Albata (Albatra?)	Cu, 58; Zn, 23; Ni, 19; Pb, 1.3	
40	Albidur-aluminium	Al; etc.	
41	Albin	*v.* White brass	
42	Alco bronze	Cu; Ni	
43	Al-Cu	Al; Cu, 7–7.6; Fe, 0.4–0.9; Si; Mn; Zn	467, 534, 601 (Nos. 43–44)
44	Al-Cu, strongest	Al; Cu, 3.8	
45	Alcumite	Cu; Al, 7.5; Fe, 3.5; Ni; Mn	578, 600
46	Al-Cu-Mg (casting)	Al; Cu, 3.4–4; Mg, 0.5; Fe; Mn; Si	468, 534, 601
47	Al-Cu-Ni	Al; Cu, 2–4; Ni, 1.1–5.3	543
48	Al-Cu-Zn, strong (ingots)	Al, 83; Zn, 10–13; Cu, 3–5.5; Mn, 0.2–0.4; Fe, Pb; Si; Sn	537
49	Al-Cu-Zn, strong (cast)	Al, 80–84; Zn, 11–17; Cu, 3–5; Fe; Mn; Si	537, 601
50	Al-Cu-Zn, strong (forged)	Al, 75; Zn, 22; Cu, 3	537, 601
51	Alfénide	Nickel silver	
52	Alférium	Similar to Duriron	
53	Algiers (Alger's) metal	Sn, 95–75; Sb, 0.5–25; Cu, 5–0	476, 557
54	Alkali-resisting metal	Fe, 95; Ni, 5	481, 604
55	Allan red bronze	Cu, 70–55; Pb, 20–40; Sn, 10–5; S, 1	562
56	Allan red metal	Cu, 50; Pb, 50; S	562
	Alloy cast iron	*v.* Index Nos. 870 and 974	
	Alloy No	For certain alloys known by numbers, *v.* p. 381	
	Alloy steels	For list, *v.* p. 390	
57	Al-Ni-Ti	Al, 98; Ni, 2; Ti, 0.4	543
58	Al-Ni-Zn	Al, 85; Ni, 10; Zn, 5	
59	Alpakka	Cu, 64; Zn, 19; Ni, 15; Ag, 2; Fe; Sn; Pb	475, 480
60	Alpax (Pacz patents)	Al; Si, 12–14; Fe, ≯ 0.8; K, or Na, 0.05	468, 543, 599, 601
61		Al; Si, 5–6; Fe, ≯ 1.0; K, or Na, 0.05	468, 543, 601
62	Aludur	Al; Si, 0.7; Mg, 0.5; Fe, 0.45; Cu	459, 475, 536, 601
63	Aluman	Al, 88; Zn, 10; Cu, 2	468, 537
64	Alumel	Ni, 94; Mn, 2.5; Al, 2; Si, 1; Fe, 0.5	
65	Aluminite (cast)	Al, 73; Zn, 23; Cu, 2.7; Fe, 0.4; Si, 0.2	537, 601
	Aluminium alloys* known by letter or number:		
	Aluminum Co. of America, casting alloys:		
66	No. 12†	Al; Cu, 8; Fe, 0.5–1.75; Si, 0.3–0.5	459, 467, 475, 533, 534, 537–542, 601 (Nos. 66–76)
67	No. 31	Al, 82; Zn, 15; Cu, 3	
68	No. 43	Al; Si, 5; Fe, ≯ 1	
69	No. 45	Al; Si, 10	
70	No. 47‡	Al; Si, 12.5	
71	No. 100	Al, ≮99	
72	No. 106	Al; Mn, 2	
73	No. 109	Al; Cu, 12.5	
74	No. 112	Al; Cu, 6–8; Zn, ≯ 2.5; Fe, ≯ 1.5	
75	No. 145	Al; Zn, 10; Cu, 2.5; Fe, 1.25	
76	No. 195	Al; Cu, 4	
	Aluminum Co. of America, wrought alloys:		
77	No. 3S	Al, 99; Mn, 1.5	468, 542
78	No. 5S	Al, 95; Cu, 2; Zn, 2; Mn, 1.5	
79	No. 8	Al, 95; Cu, 4; Si, ≯ 0.5; Fe, ≯ 0.5	467, 534, 601
80	No. 8S	Al, 67; Zn, 33	468, 537
81	No. 15S	Al; Cu; Zn	
82	No. 17S§	Al, ≮92; Cu, 3.5–4.5; Mn, 0.4–1.0; Mg, 0.2–0.75	468, 534, 601, 608
83	No. A 17S§	Al; Cu, 2.5; Mg, 0.3; Mn, 0	534
84	No. B 17S§	Al; Cu, 3.5; Mg, 0.3; Mn, 0	534
85	No. 25S	Al, 92; Cu, 3.9–5; Mn, 0.5–1.1; Si, 0.5–1	534, 601
86	No. 51S	Al; Si, 0.6–1.2; Mg, 0.45–0.8	536, 601
		The above alloys often contain Fe, Mn, Ni, Si, Sn, Zn in subordinate amounts.	
	A. S. T. M. casting alloys, Spec. B26–21:		
87	A‖	Al; Cu, 7–8.5; impurities, ≯1.7	467, 534, 537, 600, 601 (Nos. 87–89)
88	B	Al; Cu, 8.5–11; impurities, ≯ 1.7	
89	C	Al; Cu, 9–14; impurities, ≯ 1.7	

* Resists acid mine water.
† Modified.

* Many of the recently developed aluminium alloys, although having very varied mechanical properties, have not yet acquired specific names, nor universally used designations. Accordingly, a list of alloys bearing manufacturers' numbers and society specification numbers is included in this table. Some consistent nomenclature is needed, as for instance, there are three alloys labeled "A," two labeled "No. 31," etc.
† Generally known and manufactured in America under this name.
‡ Modified.
§ Duralumin.
‖ "No. 12" alloy.

Index No.	Name	Composition	Page
90	D	Al; Zn, 12.5–14.5; Cu, 2.5–3.0; impurities, $\ngtr$1.7, Pb, $\ngtr$0.1	537–541, 601
91	E	Al; Cu, 2–2.5; Mn, 0.75–1.25; impurities, $\ngtr$1.0	534, 601
	A. S. T. M. casting alloys, Spec. B26–25T:		
92	A	Al, $\nless$96.5; Cu, 1–1.5; Mn, 0.7–2; Fe, $\ngtr$0.5; Si, $\ngtr$0.5; Mg; Zn	534
93	B	Al, $\nless$92.5; Si, 4.5–6; Fe, $\ngtr$1.0; Cu, $\ngtr$0.6; Mn, $\ngtr$0.2; Zn, $\ngtr$0.2; Mg	468, 543, 601
94	C*	Al, $\nless$90; Cu, 7.0–8.5; Zn, $\ngtr$0.2; (Fe + Si + Mn + Zn + Sn), $\ngtr$1.7	467, 534, 537–541, 601
95	D	Al, 88–92; Cu, 6.0–8.0; Zn, $\ngtr$2.5; Fe, $\ngtr$1.5; (Si + Mn + Sn), $\ngtr$10 This specification will supersede B26–21, above, when adopted.	467, 537–541, 601
	N. P. L. alloys	For the more important of these, v. Index Nos. 1, 184, 520, 611, 1490, 1491	
	S. A. E. casting alloys:		
96	No. 30*	Same as Index No. 94	
97	No. 31	Al, $\nless$81; Zn, 12.5–14.5; Cu, 2.25–3.25; (Si + Fe + Mn + Sn), $\ngtr$1.7	537–541, 601
98	No. 32	Al, $\nless$85.5; Cu, 11–13.5; Zn, $\ngtr$0.2; (Si + Fe + Zn + Mn + Sn), $\ngtr$1.7	467, 534, 539–541, 601
99	No. 33	Same as Index No. 95	
100	No. 34	Al, $\nless$87; Cu, 9.25–10.75; Fe, 0.9–1.5; Mg, 0.15–0.35; other elements, $\ngtr$0.75	467, 533
101	No. 35	Same as Index No. 93	
	For B. E. S. A. Specifications	v. p. 386	
102	Aluminum brass	Cu, 71–55; Zn, 26–42; Al, 1–6	556
103	Aluminum bronze	Cu, 99–89; Al, 1–11 (name also used where other elements are present in smaller amounts than Al)	464, 475, 477, 573–578, 600, 601, 606
104	Aluminum iron bronze	Cu, 89–85; Al, 6–9.5; Fe, 3.5–7.5; Mn; Pb; P	578, 579
105	Aluminum magnesium bronze	Cu, 95–90; Al, 5–10; Mg, 0.5	
106	Aluminum manganese bronze	Cu, 89; Al, 9.6; Mn, 1.2	579, 600
107	Aluminum nickel	Ni, 94; Al, 6	
108	Aluminum nickel	Ni, 76.4; Al, 23.6	
109	Aluminum nickel bronze	Cu, 85; Al, 5–10; Ni, 10–5	581, 600
110	Aluminum silver	Al, 95; Cu, 5	534, 601
111	Aluminum silver	Cu, 57; Ni, 20; Zn, 20; Al, 3	
	Aluminum solders:		
112	Bates	Al, 70; Zn, 30	468, 536
	Bureau of Standards:		
113	SN1	Sn, 78; Al, 9; Zn, 8; Cd, 5	
114	SN2	Sn, 69; Zn, 26; Al, 2.4; P, 2.4	
115	SN3	Sn, 86; Zn, 9; Al, 5; P, 0.25	
116	SN4	Sn, 86; Zn, 9; Al, 5	
117	ZN1	Zn, 75; Cd, 20; Al, 5	
118	Geophysical Laboratory, Carnegie Institution	Zn, 90; Al, 6; Cu, 4	546
119	Roesch	Zn, 50; Sn, 49; Sb, 0.7; Cu, 0.2	
120	Seifert	Sn, 73; Zn, 21; Pb, 5; P-Sn, 1	
121	So-luminum	Sn, 55; Zn, 33; Al, 11; Cu, 1	
122	Sterling	Sn, 62; Zn, 15; Al, 11; Pb, 8.3; Cu, 2.5; Sb, 1.2	
123	U. S. patent 1 332 899	Sn, 41; Zn, 28; Cu, 3; Mn, 0.6; Al, 0.1	
124	U. S. patent 1 333 666	Pb, 92; Cd, 8 There are a host of Al solder patents, many of doubtful value or worthless.	551
125	Wüst	Zn, 50; Al, 30; Cu, 20	546
126	Wüst No. 2	Zn, 65; Al, 20; Cu, 15	546
127	Aluminum steel	Steel deoxidized with Al (Al usually less than 0.2 %).	529
128	Aluminum steel	Fe; Al, $\ngtr$15; C, $\ngtr$0.9	529

* "No. 12" alloy.

Index No.	Name	Composition	Page
129	Aluminum tin bronze	Cu, 86; Sn, 10; Al, 2.5; Zn, 2	
130	Aluminum titanium bronze	Cu, 90–89; Al, 9–10; Fe, 1; Ti, Tr.	577, 601
131	Alsen (Alzene)	Al, 66.6; Zn, 33.3	468, 536
132	Alzinc	v. Sibley casting alloy	
133	Amaloy	Ni; Cr; W	
134	Amax metal	Cu, 81; Sn, 11; Pb, 7.4; P, 0.3	562
135	Ambrac (30 %)	Cu, 65; Ni, 30; Zn, 5	480
136	Ambrac	Cu, 75; Ni, 20; Zn, 5; Mn, 0.5	480, 601, 606
137	American alloy (so-called in Europe)	Al, 95; Cu, 3; Mg, 1; Mn, 1	468, 534, 601
138	American silver (cast)	Cu, 58–49; Zn, 21–24; Ni, 15–24; Mn, < 4; Sn; Fe; Pb; Al	475, 480
139	American silver (cast)	Cu, 59; Zn, 23; Ni, 11; P-Sn, 5; Pb, 3; Al, 1.5	
140	Amervan	Fe, 63.5; V, 35	
141	Ampco (bronze)	Cu; Al, 7–11; Fe, 1–3	578, 601
142	Anaconda bronze	Cu, 90; Sn, 10	559, 601
143	Anatomical alloy (Fusible)	Bi, 54; Sn, 19; Pb, 17; Hg, 11; Cd	
144	Antifriction alloys (v. *also* p. 372)	Pb, 88–79; Sb, 12–20; Sn, 0–10; Cu; Zn	557
145	Antimonial lead	Pb, 100–75; Sb, 0–25	475, 557
146	Apex	Fe; Ni	
	Apex bronze	v. Sillman bronze	
147	Aphtit	Cu, 75–70; Ni, 20–21; Zn, 2.4–5.5; Cd, 1.8–4.5	480, 601
148	Argental	Cu, 85; Sn, 10; Co, 5	
149	Argental	Al, 75–60; Ag, 15–16; Zn, 7.5–20; Cu, 3.5–5	
150	Argentalium	Al; Ag, < 5; Mg, 0.1–1	
	Argentan:	Nickel silver	
151	Berlin	Cu, 56; Zn, 29; Ni, 16	480
152	Berlin castings	Cu, 48; Ni, 24; Zn, 24; Fe, 3.6	
153	Chinese	Cu, 40; Ni, 32; Zn, 25; Fe, 2.6	
154	French	Cu, 50; Zn, 31; Ni, 18	480
155	Resistance	Cu, 56; Ni, 26; Zn, 18; Fe, 1	
156	Russian	Cu, 64; Ni, 18; Zn, 18; Fe, 0.3; Pb, 0.3	480
157	Russian (cast)	Cu, 58; Ni, 20; Zn, 19; Fe, 3.2	
158	Sheet	Cu, 65–40; Zn, 17–32; Ni, 15–20; Fe	475, 480
159	Argentan solder	Zn, 57; Cu, 35; Ni, 8	
	Argent français	v. *also* Mousset's silver	
160	Odessa	Cu, 43; Ag, 33; Zn, 16; Ni, 8.5	
161	Rouls	Cu, 35–50; Ni, 25–30; Ag, 20–40	
162	Argentin	Sn, 85; Sb, 14.5; Cu, 0.5	475
163	Argilite	Al, 90; Cu, 6; Si, 2; Bi, 2	
164	Argosoil (Argozie)	Cu, 54; Zn, 28; Ni, 14; Sn, 2; Pb, 2	
165	Argusoid	Cu, 49–56; Zn, 23–31; Ni, 21–13; Sn, 0–4; Pb, 0–35	
166	Argyroid (Argiroide)	Nickel silver	
167	Argyrolith	Nickel silver	
168	Argyrophan	Nickel silver	
169	Arko	Cu, 80; Zn, 20	555, 601
170	Armco iron	Fe, 99.80–99.94; (P + S + Si + C + Mn), < 0.14	470, 600, 602, 606
171	Armstrong (heat resisting stainless steel)	Fe; Cr, 12; Si, 5; C, 0.5	
172	Arsenic bronze	Cu, 80; Sn, 10; Pb, 9.5; As, 0.8	562
173	Ascoloy	Fe; Cr, 14	508, 600
174	Ashberry metal (Ashberrium)	Sn, 78–80; Sb, 14–19; Cu, 0–3; Zn, 0–2.8	557

A. S. T. M. alloys:

The American Society for Testing Materials publishes standard specifications for engineering materials every three years, *viz.*, 1924, 1927, etc. Tentative standards, not yet adopted, but under consideration are published yearly on Oct. 1.

Index No.	Name	Composition	Page
	Many of these specifications do not define composition completely, but specify limits for tensile properties, weight per unit area, microstructure, etc.		
	Specification numbers preceded by "A" are for ferrous materials and by "B" for non-ferrous materials. The first part of number is the serial number of the specification, and the second part denotes the year of adoption. Numbers followed by "T" denote tentative standards.		
175	Aterite (cast)	Cu, 67; Zn, 17; Ni, 14; Fe, 1.6; Pb; Mn; Al	
176	Aterite (cast)	Cu, 55–36; Ni, 35–44; Zn, 5–0; Fe, 5–20	
177	Aterite (rolled)	Cu, 82–65; Zn, 20–23; Ni, 10–12; Fe, 15–8; Mn; Pb	
178	Aterite (rolled)	Cu, 47; Zn, 38; Ni, 11; Mn, 2.2; Fe, 1.9	
179	Atha's 2600 (*v. also* Rezistal)	Fe; Ni, 22; Cr, 8; Si, 1.75; Cu, 1.0; C, ≯0.5; Mn, 0.7	
180	ATG alloy	Ni, 60; Fe, 26; Cr, 10; W, 4	
	Automotive steels:		
	The Society of Automotive Engineers (U. S. A.) has the following system of numbering steels:		
	The first figure indicates the class of steel (*v.* below); the second figure in the case of alloy steels gives the approximate percentage of the predominant alloying element; the last two or three figures indicate the carbon content in hundredths of 1 %.		
	The class numbers are as follows: 1. C steels; 2. Ni steels; 3. Ni-Cr steels; 4. Mo steels; 5. Cr steels; 6. Cr-V steels; 7. W steels; 9. Si-Mn steels		
	Thus SAE2340 is a Ni steel of *ca.* 3 % Ni and from 0.35–0.45 % C. SAE71360 is a W steel of *ca.* 13 % W and *ca.* 0.60C		
181	Auer metal (Pyrophoric)	Fe, 35; Ce, 35; La, 24; Yb, 3; Er, 2	
182	Auer metal, cheap	Fe, 53; Mn, 30; Sb, 10; Misch metal, 7	
	Austrian alloy	*v.* Spandau alloy	
183	Awaruite (natural)	Ni, 75; Fe, 25	
184	"B" alloy	Al; Zn, 25; Cu, 3	*537*, 601
185	Babbitt (genuine)	Sn, 89; Sb, 7.3; Cu, 3.7	*476, 557*
	Babbitt metals	Pb and Sn base bearing alloys	
186	Bahn Metall	Pb; Ca, 0.7; Na, 0.6; Bi, 0.04	*556*
187	Bario (sheet)	Ni, 90; Cr, 4.3; W, 1.2; Si, 0.3; Co; Cu; Fe	
188	Bario-metal (hard)	Cr, 30; Co, 30; W, 25; Mn, 10; Ti, 5	
189	Bario-metal (soft)	Co, 60; Cr, 20; W, 20	
190	Baros	Ni, 90; Cr, 10	467
191	Basic bessemer pig	Fe; C, 3.5–4; P, 2–3; Si, ≯1; Mn, ≯0.5; S, ≯0.05	*476*
192	Basic low phosphorous pig	Fe; C, 3.5–4; Mn, 1–2.5; Si, ≯1.25; P, 0.1–1; S, ≯0.05	*476*
193	Bath metal	Cu, 83; Zn, 17	*475, 555*
194	Bath metal	Cu, 55; Zn, 45	*470, 555*
195	Battery copper	Cu, 94; Zn, 6	*469, 555*
196	Battery plates	Pb, 94; Sb, 6	*557*
197	Battery plates	Zn, 63; Sn, 21; Pb, 12; Cu, 3.2	
198	Baudrin's (Baudoin's?) alloy	Cu, 72; Ni, 17; Zn, 7.1; Sn, 2.5; Co, 1.8; Al, 0–0.5	
199	B. E. 4 alloy (Bureau of Engineering, U. S. N.)	Al; Cu, 4; Mg, 0.25; Fe, ≯0.5; Si, ≯0.1	*467, 534, 601*
	Bearing alloys:	For a list of index numbers of bearing alloys, *v.* p. 391. The ranges of compositions of the different types are given here, and also some A. S. T. M. and S. A. E. bearing alloy specifications.	
	Bronzes:		
200	Cu-Pb-(S)	Cu, 70–30; Pb, 30–70; S, ≯1	561, 562
201	Cu-Pb-Sn-(S)	Cu, 84–50; Pb, 8–40; Sn, 6–10; S	561, 562
202	Cu-Sn-Pb-Sb	Cu, 80; Sn, 16; Pb, 2; Sb, 2	
203	Cu-Sn	Cu; Sn, ≯20	475, 559
204	Cu-Sn-P	Cu; Sn, ≯20; P, ≯1	560, 601
205	Cu-Sn-Zn	Cu, 86–83; Sn, 8.8–15; Zn, 1–7.5	476, 563
206	Cu-Sn-Zn-Mn	Cu, 86; Sn, 6; Zn, 5; Mn, 2.7	
207	Cu-Sn-Zn-Pb	Cu, 88–75; Sn, 7–14; Zn, 2–9; Pb, 1–9	566
208	Cu-Sn-Zn-Pb-P	Cu, 82; Sn, 14; Zn, 2; Pb, 1; P, 1	*566*
209	Cu-Zn-Sn	Cu, 77–75; Zn, 14–21; Sn, 4–9	
210	Cu-Zn-Sn-Pb	Cu, 67; Zn, 28; Sn, 4.3; Pb, 1.4	
	A. S. T. M. Spec. B31-21 Grade:	Cu Sn Pb Max. Zn P Max. total impurities	
211	1	85 10 5 0.27 ≮0.7 0.50	562
212	2	80 10 10 0.50 ≮0.7 0.75	562
213	3	80 10 10 2.00 ≯0.05 2.50	562
214	4	77 8 15 0.50 ≯0.25 0.75	562
215	5	73 7 20 0.50 ≯0.05 1.00	562
216	6	70 5 25 0.50 0.00 1.00	562
		Fe, ≯0.25; Sb, ≯0.50; Al, 0 for all; S, ≯0.05 for 1–4 and ≯0.25 for 5 and 6	
	A. S. T. M. Spec. B22-21:		
217	A	Cu; Sn, ≯20; P, ≯1.0 } Impurities, ≯0.50	475, 559, 560, 601
218	B	Cu; Sn, ≯17; P, ≯1.0 } Impurities, ≯0.50	476, 559, 560, 601
	White metals, lead base:		
219	Pb-Sb	Pb, 100–80; Sb, 0–20	475, 557
220	Pb-Sb-Sn	Pb, 86–60; Sb, 10–20; Sn, 1–20	557
221	Pb-Sb-Sn-Cu	Pb, 78–68; Sb, 17–21; Sn, 7.3–9.6; Cu, 0.4–2	557
222	Pb-Sn-Sb	Pb, 80–40; Sn, 10–45; Sb, 10–20	557
223	Pb-Sn-Sb-Cu	Pb, 83–46; Sn, 7.7–40; Sb, 7.7–17; Cu, 0.5–8 (For lead hardened with other elements, *v.* Index Nos. 186, 390, 602, 867, 1433)	557
	A. S. T. M. Spec. B23-18T* Grade:	Pb Sb Sn Cu Max. As	
224	6	63.5 15 20 1.5 0.15	557
225	7	75 15 10 0.5† 0.20	
226	8	80 15 5 0.5† 0.20	557
227	9	85 10 5 0.5† 0.20	
228	10	83 15 2 0.5† 0.20	
229	11	85 15 0.5† 0.25	*557*
230	12	90 10 0.5† 0.25	*557*
231	S. A. E. Spec. 13*	Pb, ≯86; Sb, 9.25–10.75; Sn, 4.5–5.5; Cu, ≯0.5; As, ≯0.2	557
232	S. A. E. Spec. 14*	Pb, ≯76; Sb, 14–16; Sn, 9.25–10.75; Cu, ≯0.5; As, ≯0.2	557
	War Service Assn. of Mfrs. of Solder and Bearing Metals*		
233	Grade B	Pb, 46; Sn, 45; Sb, 7.5; Cu, 1.5‡	
234	Grade C	Pb, 60; Sn, 30.5; Sb, 8.5; Cu, 1‡	
	White metals, tin base:		
235	Sn-Pb-Sb-Cu	Sn, 74–42; Pb, 12–40; Sb, 9.5–16; Cu, 1–4.7	557
236	Sn-Sb-Cu	Sn, 91–72; Sb, 6–26; Cu, 2–9	476, 557
237	Sn-Sb-Pb	Sn, 75; Sb, 15; Pb, 10	
238	Sn-Sb-Pb-Cu	Sn, 75–70; Sb, 12–15; Pb, 9–11; Cu, 3–11; Fe; Zn	476, 557
239	Sn-Zn-Cu	Sn, 72; Zn, 27; Cu, 1.3	
	A. S. T. M. Spec. B23-18T Grade*:	Sn Sb Pb Cu Max. As	
240	1	91 4.5 ≯0.35 4.5 0.10	557
241	2	89 7.5 ≯0.35 3.5 0.10	557
242	3	83.3 8.3 ≯0.35 8.3 0.10	557
243	4	75 12 10 3 0.15	*557*
244	5	65 15 18 2 0.15	*557*

* Zn and Al, 0.

† Maximum.

‡ Fe, ≯0.08; As, ≯0.15.

Index No.	Name	Composition	Page
245	S. A. E. Spec. 10*†	Sn, ≮90; Cu, 4–5; Sb, 4–5; Pb, ≯0.35	557
246	S. A. E. Spec. 11*†	Sn, ≮86; Cu, 5–6.5; Sb, 6–7.5; Pb, ≯0.35	
247	S. A. E. Spec. 12*†	Sn, ≮59.5; Pb, ≯26; Sb, 9.5–11.5; Cu, 2.25–3.75	
	War Service Assn. of Mfrs. of Solder and Bearing Metals		
248	Grade A*	Sn, 61.5; Pb, 25; Sb, 10.5; Cu, 3; As, ≯0.15	*557*
	White metals, zinc base:		
249	Zn-Cu-Sn-Sb	Zn, 88; Cu, 8; Sn, 2; Sb, 2	
250	Zn-Sn-Al-Pb-Cu	Zn, 55; Sn, 23; Al, 20; Pb, 1.3; Cu, 0.6	
251	Zn-Sn-Cu	Zn, 85–67; Sn, 10–30; Cu, 4.2–7.4	
252	Becket alloy	Fe; Cr, 25–30; Si, 3; C, 1.5–3	
253	Bell brass	Cu, 64; Zn, 35; Sn, 0.8	*556*
	Bell metals:		
254		Al, 83; Mn, 10; Cd, 7	
255		Cu, 75–80; Sn, 25–20	559, 561
256	Herbohn	Cu, 71–60; Sn, 26–35; Zn, 2.7–5.0	
257	Japanese kara kane	Cu, 72–61; Sn, 14–25; Pb, 0–14; Zn, 0–9.4; Fe, 0–3.0	
258	Musical	Cu, 84; Sn, 16	*475*, 559
259	Bemal	Cu, 70; Zn, 29; P, 0.45; Fe, 0.15	*469, 555*
260	Benedict metal	Cu, 86–84; Ni, 14–16; C, ≮0.04	*480*
261	Benedict nickel	Cu, 79; Ni, 20; Fe, 0.36	*480, 601*
262	Benedict plate	Cu, 57; Zn, 28; Ni, 15	*480*
263	Berlin alloy	Cu, 63–52; Zn, 31–26; Ni, 6–22	*480, 601*
264	Bernda metal	A high tensile brass	
265	Bersch bearing alloy	Al, 93; Ni, 7	*543*
266	Berthier's alloy	Cu, 68; Ni, 32	*601*
267	Berthier's alloy	Cu, 72; Zn, 25; Pb, 2; Sn, 1.2	
	B. E. S. A. alloys	British Engineering Standards Assn. Spec. *v.* p. 386	
268	Best bronze	Cu, 90; Zn, 10	*469, 555*
269	Biddery	Zn, 90–84; Cu, 6.3–11; Pb, 2.5–3; Sn, 0.8–1.4	
270	Bierman tungsten bronze	Cu, 95; Sn, 3.4; W, 1.6	
271	Bilgen-bronze	Cu, 97; Sn, 1.9; Fe, 0.5; Pb, 0.2	*559*
272	Birmingham platinum	Zn, 79–53; Cu, 20–47; Fe, 0.3	*465, 546*
273	Bismuth brass	Cu, 52; Ni, 30; Zn, 12; Pb, 5; Bi, 1	
274	Bismuth brass	Cu, 47; Ni, 31; Zn, 21; Sn, 1; Bi, 1	
275	Bismuth bronze	Cu, 45; Ni, 33; Zn, 22; Sn, 16; Bi, 1	
276	Bismuth bronze	Cu, 53; Zn, 20; Sn, 15; Ni, 10; Bi, 1; Al, 0.1	
	Black heart	*v.* Index No. 836	
277	Blanko-blech	Cu, 80; Ni, 20	*480, 601*
278	Blatt gold	Cu, 77; Zn, 23	*555, 601*
279	Blatt-silver	Sn, 91; Zn, 8.3; Pb, 0.4; Fe, 0.2	
280	Bloch's alloy	Co, 54; Ni, 45; Si, 0.9; C, 0.3; Mn; P; S	
281	Blue gold	Au, 75; Fe, 25	
282	Bobierre metal	Cu, 66–58; Zn, 34–42	*555, 601*
283	Böhler magnet steel	Fe; W, 6.3; C, 0.7; Mn; P; S; Si	472
284	Böhler rapid steel	Fe; W, 14; Cr, 3.9; C, 0.7	472
285	Böhler super rapid steel	Fe; W, 15; Cr, 3.7; C, 0.8; V, 0.2; Mo, 0.2; Mn; P; S; Si	472
286	Borcher's non-corrosive alloys	Cr, 65; Fe, 35	
287	Borcher's non-corrosive alloys	Co, 35; Ni, 35; Cr, 30	
288	Borcher's non-corrosive alloys	Co, 34; Ni, 34; Cr, 30; Ag, 2	
289	Borcher's non-corrosive alloys	Co, 35; Ni, 35; Cr, 30; Mo, 0.5–5	
290	Borcher's non-corrosive alloys	Fe, 60; Cr, 36; Mo, 4	
291	Boronised copper	Cu deoxidised with B, no excess present	558
292	Boron steel	Fe; B, 0.06–0.4; C, 0.45–0.16; Al; Si; Mn	530
293	Bourbonnes	Sn, 51; Al, 49; Fe, 0.3; Cu, 0.3.	
	Brass	For list of brasses, *v.* p. 389	
	Brass ingots, A. S. T. M. Spec. B30–22*: No.	Cu Zn Sn Pb Max. Fe	
294	1	87 3 8 ≯2 0.25	
295	2	85 5 5 5 0.35	561
296	3	83 7 4 6 0.35	*561*
297	4	77 10 3 10 0.40	*561*
298	5	76 16 2 6 0.40	
299	6	65 33 ≯1 2 0.50	
300	7	60 37 ≯1.5 3 1.00	
	For B. E. S. A. Specifications	*v.* p. 386	
301	Brazing brass	Cu, 80–75; Zn, 20–25; Pb; Fe	460, *555*
302	Bridge bronze A	Cu, 80; Sn, 20; P, 0.1	*475, 559*
303	Bridge bronze B	Cu, 85; Sn, 15; P, 0–1	*475, 560*
304	Bridge bronze C	Cu, 80; Sn, 10; Pb, 10; P, 0.7–1	*562*
305	Bridge bronze D	Cu, 88; Sn, 10; Zn, 2; P, 0.3	*476, 566*
306	Bright cap gilding	Cu, 90; Zn, 9.9; Pb, 0.4	*469, 555*
307	Brightray	Similar to Chromel A	
308	Bristol brass	Cu, 76–61; Zn, 24–39	*555, 601*
	Brittania metal:		
309	Cast	Zn, 48; Sn, 48; Cu, 3; Pb, 1; Sb, 1	*476*
310	Cast	Sn, 91–85; Sb, 9–11; Zn, 0–3; Cu, 0.2–1	*476, 557*
311	English	Sn, 90–85; Sb, 5–10; Cu, 1–3; Zn, 0–3; Bi, 0–2	*557*
312	German	Sn, 94–70; Sb, 3.7–15; Cu, 1.8–5; Pb, 0–9; Zn, 0–5	*557*
313	Plate (Ludenscheidt)	Sn, 72; Sb, 24; Cu, 3.9	
314	Plate	Sn, 91–90; Sb, 7–8; Cu, 1.4	*557*
315	Spoons	Sn, 88–85; Sb, 5.6–15; Bi, 1–5; Cu, 0.1–3.7; Zn, 0–1.5	
316	Brix	Ni, 75–60; Cr, 15–20; Cu, 5; Si, 4; Ti, 3; Al, 2; W, 1–4; B, 1; Mn	
317	Brolunick	Cu; Al; Ni	
	Bronze	For list of bronzes, *v.* p. 389	
318	Bronze powder	Cu, 84; Zn, 16	
319	Bronze wire	Cu, 99; Sn, 1.2; P, 0.05	*565*
320	B. T. G. steel	Ni, 60; Fe, 25; Cr, 12; Mn, 2; C, 0.5	*467, 480*
321	Burr metal	Cu, 90; Zn, 10	*469, 555*
322	Butt brass	Cu, 64; Zn, 36; Pb, 1	*555, 602*
323	Button alloy	Cu, 60–50; Zn, 30–45; Sn, 0–10	*555, 556, 601*
324	Button brass	Cu, 90; Zn, 10; Sn, 0.5	*465, 555*
	Cadmium silver	*v.* Index No. 1330	
325	Caedit	Similar to Stellite	
326	Calido, Elalco	Ni, 60; Fe, 24; Cr, 16	*467*
327	Calido, Elalco	Ni, 64; Fe, 25; Cr, 8; Mn, 3	
328	Calite A	Fe; Ni, 35; Cr, 15; C, 0.8	*512*
329	Calite B	Fe; Cr, 18; Ni, 6; C, 1.5	*512*
330	Calorite	Ni, 65; Fe, 15–23; Cr, 12; Mn, 0–8	
331	Camelia metal	Cu, 70; Pb, 15; Zn, 10; Sn, 4.2; Fe, 0.5	*561*
332	Can-metall (German)	Pb, 95; Ca, 1.75; Cu, 1.35; Sr, 1; Ba, 1	*556*
333	Cap gilding	Cu, 90; Zn, 10	*469, 555*
334	Capsule metal	Pb, 92; Sn, 8	*467, 557*
335	Carbon bronze	Cu, 75; Pb, 15; Sn, 9.7	*561*
	Carbon steels	For list, *v.* p. 390	
336	Carbondale silver	Cu, 66; Ni, 18; Zn, 16	*480*
337	Carburite (recarburizer)	C, 47–48; Fe, 28; S, 0.3; P, 0.2; binder	
338	Careco	A white bearing alloy	
339	Cartridge brass	Cu, 67–70; Zn, 33–30; Pb; Fe	469, 555
340	Cartridge gilding	Cu, 93; Zn, 7	*469*, 555

* Zn and Al, 0; Fe, ≯0.08.
† As, ≯0.1; Bi, ≯0.08.

* S, ≯0.05; Al, 0 except 0.3 % allowable in 6 and 7; Sb, ≯0.25 in 1–3, and ≯0.35 in 4, and ≯0.20 in 6 and 7; P, ≯0.05 in 1–5 and ≯0.02 in 6 and 7. *v. also* p. 372.

Index No.	Name	Composition	Page
341	Case-hardening steel	Fe; C, ≯0.20; Mn; Si; P; S (or low carbon alloy steel)	470, 488, 600, 606
	Cast iron	For list, *v.* p. 390	
	Cast steel	*v.* Index No. 1335. (The name is also applied to crucible steel)	
342	Ceco	Cu, 62.5; Pb, 32; Sn, 4.6; Ni, 0.9; Fe, < 0.03	*562*
343	Celsit	Similar to Stellite	
344	Cerium steel	Fe; Ce, 0.2–0.6; C, 0.4; Mn, 0.7; Si, 0.4–0.8	531, 605
345	Chain bronze	Cu, 95; Sn, 4.9; P, 0.1	*560, 601*
346	Chain iron (A. S. T. M. Spec. A56–24)	Grade AA: Mn, ≯0.10; Grade A: Mn, ≯0 2 (strength specified)	
347	Chain steel (A. S. T. M. Spec. A56–24)	Grade BBB: P, ≯0.04; S, ≯0.04 (strength specified)	
348	Chamet bronze	Cu, 62; Zn, 38	*555, 601*
349	Charcoal pig iron (Lake Superior)	Fe; C, 3–4; Si, 0–2.6; P, 0.15–0.25; Mn, 0.3–07; S, ≯ 0.02	
350	Charpy phosphor bronze	Cu, 85; Sn, 12–13; P, 0.4–0.5	*560*
351	Checo (dental)	Ag, 89; Sn, 10; Pt, 1	
352	Chemical lead	Pb; Cu, 0.04–0.08; Ag, 0.005–0.015; Bi, ≯0.005	461, 475, 556
353	Chilled cast iron wheels (A. S. T. M. Spec. A46–24) (Key No. 117, p. 497)	Total C, ≮3.25; combined C, ≯0.85; Si, 0.45–0.75; Mn, 0.5–0.75; P, ≯0.4; S, ≯0.15	*470, 476,* 497
354	China silver	Nickel silver	
355	Chinese bronze	Cu, 83–72; Pb, 10–20; Zn, 0.7–14; Sn, 1–13; Fe (*v. also* Index No. 912)	*561*
356	Chinese silver	Cu, 58; Zn, 17.5; Ni, 11.5; Co, 11; Ag, 2	
357	Chinese speculum	Cu, 81; Sn, 11; Sb, 8.5	
358	Chinese speculum (Elsner's)	Cu, 81; Pb, 9; Sb, 8	
359	Christofle metal	Silver-plated German silver (Ag, 2)	
360	Chromal steel	Fe; Cr, 0.8; Mn, 0.8; Mo, 0.8; C, 0.3	*472, 605*
361	Chromaluminium	Al; Cr	
362	Chromax (Kromax?)	Ni, 75; Cr, 25	
363	Chromax bronze	Cu, 67; Ni, 15; Zn, 12; Al, 3; Cr, 3	
364	Chrome iron	Similar to Duraloy	
365	Chromel No. 502	Fe, 55; Ni, 25; Cr, 20	
366	Chromel A	Ni, 80; Cr, 20	*480, 608*
367	Chromel B	Ni, 85; Cr, 15	*467, 480*
368	Chromel C	Ni, 65; Fe, 24; Cr, 11	*467, 480*
369	Chromel D	Fe, 66; Ni, 26; Cr, 8	
370	Chromel P	Ni, 90; Cr, 10	*467*
371	Chrome-molybdenum steel	Fe; Cr, 0.5–1; Mo, 0.1–1.0; C, 0.1–0.5; Mn; Si; P; S	472, 604, 605
372	Chrome-nickel steel (ordinary range)	Fe; Ni, 1.25–3.5; Cr, 0.6–1.5; C, 0.2–0.6; Mn, ≯0.7; P, ≯0.04; S, ≯0.05; Si, low	472, 510, 518, 600, 604–608
373	Chrome-nickel steel armor plate (heavy) (Key No. 268, p. 512)	Fe; Ni, 4; Cr, 2; C, 0.33; Mn, 0.32; Si, 0.06; S, 0.03; P, 0.14 (*v. also* Projectile steel)	*472, 512*
	Chrome-tungsten steel	*v.* High-speed steel	
374	Chrome-uranium steel	Fe; Cr, 0.8; U, 0.17–0.3; C, 0.3–0.4; Mn; Si	478
375	Chrome-vanadium steel	Fe; Cr, 0.7–1.4; C, 0.15–0.6; V, 0.12–0.3; Mn, 0.3–0.9; Si, 0.2; P, ≯0.01; S, ≯0.04	472, 509, 517, 600, 604, 605
376	Chromium steel (commercial pearlitic)	Fe; Cr, 2–5; C, 0.2–0.8; Mn; Si; P; S (*v. also* p. 390)	507–509, 517, 605
377	Chrysite (dental)	Cu, 63; Zn, 37; Pb, 0.24	*555, 602*
378	Chrysokalk	Cu, 59; Zn, 40; Pb, 1	*602*
379	Chrysokalk	Cu, 91; Zn, 7.9; Pb, 1.6	*469*
380	Chrysorin	Cu, 72–63; Zn, 28–37	*555, 601*
381	Cimet	Fe; Cr, 25	
382	Chrome-silicon steel	*v.* Index No. 1235	
383	Clark's patent	Cu, 75; Ni, 14; Zn, 7.2; Sn, 1.9; Co, 1.9	
384	Clebrium	Fe; Cr, 13; Mo, 3.6; C, 2.6; Ni, 2; Si, 1.5; Mn, 0.8	
385	Clebrium	Fe; Cr, 19; Ni, 4.6; Mn, 2.8; C, 2; Cu, 2	

Index No.	Name	Composition	Page
386	Clichier metal	Pb, 40–50; Sn, 33–36; Cd, 21–14	
387	Clichier metal	Sn, 80; Bi, 15; Pb, 5	
388	Clichier metal	Sn, 48; Pb, 33; Sb, 11; Bi, 9	
389	Climax	Fe, 73; Ni, 24; Mn, 2.6	*482*
390	C. M. A. bearing metal	Pb; alkaline earth metals	*556*
391	Cobaltcrome	Fe, 80; Cr, 14; Co, 3.7; C, 1.5; Mo, 0.8; Si, 0.8	
392	Cobaltcrome	Fe, 70–60; Cr, 30–25; Co, 5–10	
393	Cobalt steel	Fe; Co, 0.5–17; C, 0.15–0.9; Mn; P; S	
	Coinage alloys	*v.* Index Nos. 975, 1249, 1250, 1326, 1327, 1329, 1330	
394	Coinage bronze	Cu, 95; Sn, 4; Zn, 1	*561*
395	Collet brass	Cu, 61; Zn, 37; Pb, 2.5	602
396	Colorado metal	Cu, 57; Ni, 25; Zn, 18	*475, 480*
397	Comet	Fe, 70; Ni, 30; Cr, 2.2; Mn, 0.8; Cu, 0.4	
	Commercial bar steel	*v.* Index Nos. 1336–1341	
398	Commercial brass, B-r	Cu, 63; Zn, 37 (rolled)	*555, 601*
399	Commercial brass, B-c	Cu, 62; Zn, 30; Sn, 6; Pb, 2 (cast)	
400	Commercial brass wire	Cu, 64; Zn, 36; Pb, 0.2; Fe	469, *601*
401	Commercial bronze	Cu, 90; Zn, 10; Pb; Fe	469, *555*
402	Commercial bronze rod	Cu, 86; Zn, 12.75; Pb, 0.75; Sn, 0.5	*469, 555*
403	Common high brass	Cu, 65; Zn, 35	*555*, 601
404	Complex English metal	Sn, 87; Sb, 6; Ni, 2; Cu, 2; W, 1.5; Zn, 1; Bi, 0.5	
	Condenser foil	*v.* Accumulator metal	
405	Constantan	Cu, 60–45; Ni, 40–55; Mn, 0–1.4; C, 0.1; Fe	464, 480, 601, 606
406	Cook's alloy	Sb, 57–69; Zn, 32–43	
407	Cooperite	Ni, 80; W, 14; Zr, 6	
408	Cooper's gold	Cu, 81–67; Pt, 19–30; Zn, 0–4	
409	Cooper's mirror	Cu, 58; Sn, 28; Pt, 9.5; Zn, 3.5; As, 1.5	
410	Cooper's pen metal	Cu, 50; Au, 25; Ag, 25	*586*
411	Cooper's pen metal	Pt, 50; Ag, 38; Cu, 12	*480, 601*
412	Copel	Cu, 55; Ni, 45	
	Copper (commercial):		
413	Arsenical lake	Cu, 99.4; As, 0.3; O, 0.2	460, 552
414	Best select	Cu, 99.5	*553, 601*
415	Electrolytic	Cu, 99.90–99.993	552, 601
416	Lake	Cu, 99.9	*552, 601*
417	Oxygenated	Cu; O, 0.04–0.2	554, 601
	Copper-manganese	*v.* Cupromanganese	
	Copper-nickel	*v.* Cupronickel	
418	Copper steel	Fe; Cu, ≯4; C, ≯1.1; Mn; Si; P; S	509
419	Cornish bronze	Cu, 78; Sn, 9.6; P, 0.8	*560, 601*
420	Corronil	Ni, 70; Cu, 26; Mn, 4	*480, 604*
421	Corrosion-resisting alloy	Pb, 91; Cu, 4.5; Ni, 4.5 (for list *v.* p. 391)	
422	Corrosion-resistant steel (Carpenter)	Fe; Cr, 9.5; C, 0.45	*470, 508*
423	Corrosiron	Fe, 85.5; Si, 13.5	*473*
424	Corsonite* A	Cu; Ni; Si	
425	Corsonite B	Cu; Co; Si	
426	Corsonite C	Cu; Fe; Si	
427	Corsonite D	Cu; Cr; Si	
428	Corsonite E	Cu; Cr	
429	Corsonite F	Cu; Co	
430	Cowles high Mn brass	Cu, 80–67; Mn, 15–18; Zn, 5–13; Al, 0–1; Si	
431	Craig gold	Cu, 80; Ni, 10; Zn, 10	
432	Crank case alloy	Al, 91–90; Cu, 7–8; Fe, 1–1.8; Zn, 0–1.8	*467, 534, 601*
433	Crescent steel	Fe; W, 6.7; Mn, 2.7; C, 2.1; Si, 0.1	
434	Crodon	Cr alloy plating	
435	Cronite	Ni, 60; Cr, 40	
436	Crotorite	Cu, 70; Mn, 30; Fe, 2	

* Name given by Mr. Corson to these alloys which were developed at the Union Carbide and Carbon Research Laboratories, Inc. *v. Metal Industry* (N. Y.) Sept., 1926.

Index No.	Name	Composition	Page
437	Crucible steel (*also called* cast steel)	Fe; C, 0.65–1.55; Mn; Si; P; S. (Graded according to "temper," one temper unit generally meaning 0.1 % C. Designation varies with manufacturer.)	470, 477, 492–497, 516–518, 600, 602, 603, 605–608
438	Cufenium	Cu, 72; Ni, 22; Fe, 6	
439	Cuivre poli	Cu, 70; Zn, 30	555, 601
440	Cuniloy	Ni, 65; Mn, 35; Cu, 25; Pb, 1	
441	Cupola malleable iron	Fe; C, 3.0; combined C, Tr.; Si, 0.9; Mn, 0.8; P, 0.2; S, 0.15	476, 497, 525, 526
	Cupro-aluminium	v. Aluminum bronze	
442	Cupromagnesium	Cu, 90; Mg, 10	
443	Cupromanganese	Cu, 90; Mn, 10	554
444	Cupromanganese tubes	Cu, 96; Mn, 4	554, 600
	Cupronickel:		
445	Bullet jackets	Cu, 85; Ni, 15; C, <0.04	480
446	Commercial	Cu, 98–60; Ni, 2–40	480, 601
447	Driving bands	Cu, 97.5–95; Ni, 2.5–5	480
448	Ingots	Cu, 50; Ni, 50	480
449	Locomotive tubes	Cu, 97; Ni, 3	480
450	No. 300 alloy	Cu, 89; Ni, 11	480
451	Sheet	Cu, 81–79; Ni, 19–21	480, 601
452	Cuprosilicon	Cu; Si, > 55	554, 594
453	Cupror	Cu, 94; Al, 5.8	574, 601
454	Cyclops No. 17 metal	Fe; Ni, 20; Cr, 7.5; Si, 1.00; Mn, 0.75; C, 0.45	604
455	Cymbal metal	Cu, 78; Zn, 22	555, 601
456	Cyprus bronze	Cu, 65; Pb, 30; Sn, 5	562
457	Daimler bearing	Cu, 76; Zn, 20; Sn, 3; Pb, 1	
458	Damar	Cu, 76; Pb, 13; Sn, 11	562
459	Damascus bronze	Cu, 77; Pb, 13; Sn, 10	562
460	Dandelion metal	Pb, 72; Sb, 18; Sn, 10	
461	D'Arcet	Bi, 50; Pb, 25; Sn, 25	
462	Dark red gold	Au, 50; Cu, 50	586
463	Davis metal	Cu, 67; Ni, 29; Fe, 2; Mn, 1.5; (C + Si), 0.5	
464	Degussa alloy	Cu, 66; Zn, 34; Fe	556, 601
465	Delatot's metal	Cu, 80; Zn, 18; Mn, 2	
466	Delhi hard iron	Fe; Cr, 17; Si, 1.5; C, 1.2	
467	Delhi tough iron	Fe; Cr, 17; Si, 1.25; Mn, 0.3; C, 0.07	
468	Delta metal	Cu, 56–54; Zn, 40–44; Fe, 0.9–1.3; Mn, 0.8–1.4; Pb, 0.4–1.8; P	464, 556, 602
469	Demo bronze	Cu, 61; Pb, 33; Sn, 4–6; Ni, 2–1	562
470	Dewrance metal	Sb, 45; Sn, 33; Cu, 22	
471	Diamond bronze	Cu, 88; Al, 10; Si, 2	
472	Diaphragm brass	Cu, 95; Sn, 3; Zn, 2	
	Die-casting alloys:		
473	....	Al, 92–82; Cu, 8–18; Fe, 0–3; Mg; Mn; Si; Zn	534, 601
474	High grade bearings	Sn, 91–84; Sb, 2–9; Cu, 4.5–8	476, 557
475	Light duty bearings	Pb, 90–80; Sb, 10–17; Sn, 10–0; Cu, 0–1	475, 557
476	Light duty bearings	Sn, 80; Pb, 10; Sb, 10	
477		Sn, 61.5; Pb, 25; Sb, 10.5; Cu, 3	
478	Soft work	Zn, 74; Sn, 15; Al, 6; Cu, 5	
479	Standard	Zn, 85; Sn, 8; Cu, 4; Al, 3	
480	Hard	Zn, 82.75; Al, 13.75; Cu, 3	546
481	Hard	Zn, 46; Sn, 31; Cu, 20; Sb, 3	
482	Strong, hard	Zn, 86.5; Cu, 10.75; Al, 2.75	546
483		Zn, 90–83; Cu, 5–11; Al, 2–5; Sn, 1–5 (*v. also* Index No. 955, and white metals)	
484	Dienett's German silver	Cu, 51; Zn, 32; Pb, 9.5; Ni, 6.4; Sn, 1.6	
485	Diesel bearings	Sn, 80; Sb, 15; Cu, 5	
486	Dilver	v. Platinite	
487	Dipping brass	Cu, 67; Zn, 33	555, 601
488	Dirigold	Cu; Al, 10: Ni, 2	582
489	Doctor metal	Cu, 88; Zn, 9.5; Sn, 2.5	
490	Dowmetal A	Mg, 92; Al, 8	544, 604
491	Dowmetal B	Mg, 88; Al, 12	544
492	Dowmetal C	Mg, 85; Al, 15	544
493	Dowmetal D	Mg, 88; Al, 8.3; Cu, 2.0; Cd, 1.0; Zn, 0.5; Mn, 0.2	544
494	Dowmetal E	Mg, 94; Al, 5.8; Mn, 0.2	544, 604
495	Dowmetal R	Mg, 90; Al, 8; Cu, 1; Cd, 1	544
496	Dowmetal T	Mg, 92; Cu, 3.8; Cd, 2; Mn, 0.2	544
497	Drawing brass	Cu, 70–67; Zn, 33–30 (*v. also* Index Nos. 1409, 1486)	469, 555, 601
498	Dudley's antifriction alloy	Sn, 98; Cu, 1.6; Pb, 0.3	
499	Dudley's bearing metals	v. Index Nos. 553, 556	
500	Dudley's phosphor bronze	Cu, 80; Sn, 10; Pb, 9.6; P, 0.8	562
501	Duke's metal	Ni, 40; Cu, 30; Fe, 30	
502	Duke's metal	Fe, 81; Cr, 12; C, 1.5; Co, 4; Si, 0.6; W, 0.4; Mn, 0.2	
503	Dumet	Fe, 54; Ni, 46; (Cu, plated)	467, 481
504	Dunnlevic and Jones antifriction	Pb, 60; Sb, 20; Zn, 20	
505	Dunnlevic and Jones antifriction	Zn, 85–80; Sb, 10; Sn, 5–8	
506	Dunnlevic and Jones antifriction	Zn, 52; Sn, 46; Cu, 1.6; Sb, 0.4	476
507	Duraloy(Key No. 191, p. 508)	Fe; Cr, 25–30; Mn, 0.6; Si, 0.5; P (sometimes only 20 % Cr)	508
508	Duralumin	Al; Cu, 3.5–5.5; Mg, 0.5–0.8; Mn, 0.5–0.8; Fe; Si	468, 534, 601, 608
509	Duralumin (imitation)	Al, 79; Mg, 11; Cu, 10; P, 0.05	
510	Duralumin, special ("Y" alloy)	Al, 92.5; Cu, 4; Ni, 2; Mg, 1.5	534, 601, 608
511	Durana metal	Cu, 65; Zn, 30; Pb, 2; Al, 1.5; Fe, 1.5	556
512	Durana metal	Cu, 59; Zn, 40; Sn, 1; Pb, 0.4; Fe, 0.3	470, 556
513	Durand's alloy	Al, 67; Zn, 33	468, 536
514	Durex	Cu, 83; Sn, 10; Graphite, 4.4–4.7	
515	Duriron	Fe; Si, 14–15; Mn, 2–2.5; C, 0.8–1.3; S, 0.05–0.2; P, 0.05–1	473
516	Duriron	Fe; Si, 14–15; Mn, 0.3–0.4; C, 0.2–0.6; P, 0.2; S, 0.05	473
517	Dutch metal (Dutch leaf, Dutch gold)	Cu, 76; Zn, 24	555, 601
518	Dynamo sheets	Fe; Si, 3–4; C, <0.1; Mn, <0.3; (P + S), <0.03	472, 584
519	Dysoid	Cu, 62; Pb, 18; Sn, 10; Zn, 10	
520	"E" alloy (rolling)	Al; Zn, 20; Cu, 2.5–3; Si, 0.2–1; Mg, 0.5; Mn, 0.5; Fe	538, 601, 608
521	E. B. D. bearing	Cu, 90–88; Sn, 10; P–Sn, 5; Zn, 2	
	Edelmessing	High tensile brass	
	Edelstahl	Alloy steel	
522	Edwards speculum	Cu, 70–63; Sn, 25–32; As, 2.4–1.6; Zn, 2.6–0	
523	Ehrhardt's metal	Zn, 89; Cu, 4; Sn, 4; Pb, 3	
524	Ehrhardt's type metal	Zn, 89; Sn, 6; Cu, 3; Pb, 2	
525	Einheitsmetall	Pb, 79; Sb, 14; Sn, 5.3; Cu, 1.5	557
	Eisenbronze	v. Iron bronze	
526	Eislers (bronze)	Cu, 94; Sn, 5.9	559, 601
	Elalco alloys	v. Index Nos. 326, 717, 830	
527	Electrical brass, B. E.	Cu, 84; Zn, 13; Sn, 3	
528	Electrometall	Al; Mg; v. Electron	
	Electron	Generic name of some Mg base alloys containing up to 12 % Al, as:	
529	Electron	Mg, 90; Al, 3–7; Zn, 2–5; Mn, 0.5	545
530	Electron	Mg, 95; Zn, 4–5; Cu, 0–0.6	545, 604
531	Electroplate	Cu, 50–70; Ni, 10–20; Zn, 5–30	475, 480, 601, 606
532	Electrotype (standard)	Pb, 93; Sb, 4; Sn, 3	
533	Electrum	Cu, 52; Ni, 26; Zn, 23	475, 480
534	Electrum	Au, 85–55; Ag, 15–45	586
535	Elephant bronze	Cu, 95.5; Sn, 3.9; P, 0.3; Fe, 0.16	464, 560, 600

Index No.	Name	Composition	Page
536	Elianite	Similar to Duriron	
537	Elinvar (Key No. 277, p. 512)	Fe; Ni, 36; Cr, 12; C, 0.8; Mn; Si, 1-2; P; S	512
538	Emperor brass	Cu, 60; Al, 20; Zn, 20	
539	English alloy	Sn, 53; Pb, 33; Sb, 11; Cu, 2.4; Zn, 1	
540	English brass	Cu, 70; Zn, 29; Pb, 0.3; Sn, 0.2	*469, 555, 601*
541	English phosphor bronze	Cu, 79; Sn, 10; Pb, 9.6; P, 1.0	*562*
542	English nickel silver	Cu, 70; Zn, 29; Pb, 0.3; Sn, 0.2	*469, 555, 601*
543	English speculum	Cu, 67; Sn, 33	*561*
544	Engraver's brass	Cu, 66; Zn, 33; Pb, 1	*469*
545	Eureka	*v.* Manganin	
	Eutectic (fusible alloys)	*v. also* p. 391	
546	M. P. 70–74°C	Bi, 50; Pb, 27; Sn, 13; Cd, 10	
547	M. P. 91.5°C	Bi, 52; Pb, 40; Cd, 8	
548	M. P. 96°C	Bi, 53; Pb, 32; Sn, 15	
549	M. P. 103°C	Bi, 54; Sn, 26; Cd, 20	
550	M. P. 145°C	Sn, 50; Pb, 32; Cd, 18	
551	Everbrite	Cu, 60–58; Ni, 35	
552	Everdur No. 50 metal	Cu, 94.5; Si, 4.5; Mn, 1	*554*
553	Ex. B metal	Cu, 77; Pb, 15; Sn, 8; P	562
554	Excello (resistance)	Ni, 85; Cr, 14; Fe, 0.5; Mn, 0.5	*467, 480*
555	Excelsior	Cu, 53; Ni, 45; Fe, 0.3	*480, 601*
556	Ex. K metal	Cu, 77; Pb, 12.5; Sn, 10.5; P	562
557	Expanding alloy	Pb, 67; Sn, 25; Bi, 8.3	
558	Extra soft steel	Fe; C, 0.2; Si, 1.3; Mn, 0.2; P; S	470, 488
559	Fahlun brilliants (Faluner Diamanten)	Sn, 60; Pb, 40	*467, 557*
560	Fahrig antifriction	Sn, 90; Cu, 10	*561*
561	Fahrite, C-5	Fe; Cr, 25; C	*508*
562	Fahrite, N-1	Fe; Ni, 35; Cr, 17	
563	Fenton's alloy	Zn, 80; Sn, 15; Cu, 5	
564	Fermet	Fe; Ni, 18; Cr, 4; Mn, 2.2; W, 0.5–1; C, 0.4; Cu, 0.3	
565	Ferro-carbon-titanium	Fe; Ti, ≮15; C, 1.5; Si, 1.4; Al, 0.8; Mn; P; S	
	Ferrochromium	Grade %C	
566	A. S. T. M. Spec. A101–25T	A 4–8 or S* (Cr, 60–75; Si; S*; Fe, balance)	
567	A. S. T. M. Spec. A101–25T	B 1.5–2 (Cr, 60–75; Si; S*; Fe, balance)	
568	A. S. T. M. Spec. A101–25T	C 1–1.5 (Cr, 60–75; Si; S*; Fe, balance)	
569	A. S. T. M. Spec. A101–25T	D < 1 or S* (Cr, 60–75; Si; S*; Fe, balance)	
570	Ferrocupralium	Cu, 81–75; Fe, 2–13.3; Al, 12.4–11.2	
571	Ferromanganese	Fe; Mn, 38–80; C, 5–7; S, ≯0.3; Si, 0.5–1; P, ≯0.1–1	473
572	Ferromanganese (A. S. T. M. Spec. A99–25T)	Mn, ≮78; Fe, balance; C, ≯7.5; Si, ≯1.0; P, ≯0.35; S, ≯0.05; *v. also* Index Nos. 1312–1314	
	Ferromolybdenum:†		
573	Regular	Fe: Mo, 50–60; C, 2.0	
574	Special	Fe: Mo, 50–60; C, 0.5	
	Ferronickel:		
575	No. 193 alloy (Driver Harris)	Fe; Ni, 30; Cr, 2 (*v. also* p. 391)	
		Grade % Si	
576	Ferrosilicon (A. S. T. M. Spec. 100–25T)	A 47–53	474
577	Ferrosilicon (A. S. T. M. Spec. 100–25T)	B 72–78	474
578	Ferrosilicon (A. S. T. M. Spec. 100–25T)	C 85–95	474
579	Ferrosilicon pig (silvery pig iron)	Fe; Si, 6–16; *v. also* Index No. 1238	
	Ferrotitanium	*v.* Index No. 565	
580	Ferrotungsten	Fe; W, 70–85; C, 0.5; Mn; Si; P; S	
581	Ferro-uranium	Fe; U, 30–40; Si, 2.5–4; C, 1; Ca; Mn; Cu; Al; P; S	
	Ferro-vanadium (A. S. T. M. Spec. 102–25T)	Grade; V; Si; C; Max. P; Max. S	
582	A	V 30–40; Si 8–15; C 3–6; P 0.25; S 0.3	
583	B	V 30–40; Si 5–8; C 1.5–3; P 0.25; S 0.3	
584	C	V 35–45; Si ≯2; C ≯1.5; P 0.15; S 0.2	
585	D	V 35–45; Si ≯2; C ≯0.75; P 0.10; S 0.1	
		Grades A–C, Al, ≯2; D, Al, ≯1	
586	Ferrozoid	Fe; Ni; C (Ni steel)	
587	Ferry alloy	Cu; Ni; Zn (Ni silver)	
588	Festel metal	Fe, 55; Co, 23; Cr, 21; C, 0.7	464
589	File metal (file bronze)	Cu, 73–51; Sn, 18–31; Pb, 8.5–7; Zn, 0–10	*561, 562*
590	Fire armor	Ni, 61; Fe, 20.5; Cr, 18.5	
591	Flame resisting alloy	Fe; Cr, 14; Ni, 9.7; Mn, 0.8; Si, 0.2; C, 0.2	
592	Flange metal (French)	Cu, 94; Sn, 5.6; Pb, 0.05	*559, 601*
593	Flange metal (German)	Cu, 92; Zn, 5; Sn, 2.5	
594	Fletcher and Emperer bearing	Al, 92; Cu, 7.5; Sn, 0.3	*536, 601*
595	Fletcher's alloy	Al, 96; Cu, 3; Sn, 1; Sb, 0.5; P-Sn, 5	
596	Flint alloy	Fe, 83; Cr, 12.5; Si, 0.5; C, 0.3	*508, 603*
597	Fontainmoreau's bronze	Zn, 99–90; Cu, 0–8; Fe, 0–1; Pb, 1–0	*465, 546*
598	Forbes metal	Zn, 54; Cu, 46	*465, 546*
599	Forging brass	Cu, 60–53; Zn, 40–43; Mn, 0–4.5	555, 556, 602
600	Fourdrinier wire	Cu, 85–80; Zn, 15–20; Sn, 0–0.4	469, *555,*
601	Foundry pig iron*	Fe; C, 3–4; Si, 1.5–3; Mn, ≯1; P, 0.5–1; S, ≯0.04–0.06	
602	Frary metal	Pb; Ba, < 2; Ca, < 1; Hg, 0.3	556
603	Free cutting bronze	Cu, 89; Zn, 10; Pb, 1.5	*469*
604	Free-turning rod brass	Cu, 62; Zn, 35; Pb, 2.6; Fe	469
605	French alloy	Cu, 58–50; Zn, 25–30; Ni, 17–20	*480*
606	French aluminium bronze (*v. also* Brolunick)	Cu, 82; Al, 7; Ni, 5.5; Fe, 4; Mn, 2	
607	Freund steel	Fe; Si, 0.7–1.3; Mn, 0.3–0.6; C, 0.1–0.15; Cr	*472, 523*
608	Frick's alloys	Cu, 69–50; Zn, 18–39; Ni, 5.5–31	*475, 480, 601*
609	Friction alloy (standard)	Pb, 50; Sn, 40; Sb, 10	*557*
	Fusible alloys	*v.* p. 391	
610	Fusible tea spoons	Bi, 45; Sn, 17; Pb, 30; Hg, 5–10	
611	"G" alloy (N.P.L.)	Al; Zn, 18; Cu, 3; Si, 0.8; Mn 0.4; Mg, 0.3; Fe, 0.2	538
612	Gear bronze	Cu, 91–78; Sn, 8.5–13; Zn, 0–3; Pb, 0–2; P, 0–2 (*v. also* Index No. 1359)	560, *601*
613	Gear steel (high duty)	Fe; Ni, 3.5; Cr, 1.5; C, 0.45–0.5	*472, 512*
614	Gedges (Geages?) metal	Cu, 60; Zn, 39; Fe, 1.5	*556, 602*
615	Genelite	Cu; Pb; Sn; graphite, < 40	
	German silver:		
616	Austrian (Gersdorf)	Cu, 60–50; Zn, 20–25; Ni, 20–25	*475, 480*
617	Best	Cu, 46; Zn, 34; Ni, 20	*480*
618	Birmingham	Cu, 62–50; Zn, 32–20; Ni, 12–30	*480, 601*
619	Common formula	Cu, 55; Zn, 25; Ni, 20	*475, 480*
620	Gilding	Cu, 95; Zn, 5; Pb; Fe	469, *555*
621	Gilding foil	Sn, 98; Cu, 2.2; Fe, 0.1	*561*
622	Gilding metal	Cu, 72–64; Zn, 23–34; Sn, 0.3–2.5; Pb, 0.3 (*v. also* Index Nos. 306, 333 and 1134)	*469, 555, 601*
623	Glass mold alloy (U. S. patent 1 360 773)	Cu, 65–55; Ni, 12–18; Zn, 11–17; Fe, 8–12; Si, 0.5–1	
624	Glievor bearing	Pb, 77; Sb, 14; Sn, 8; Fe, 1.5	*476*
625	Glievor bearing	Zn, 74; Sb, 9; Sn, 6.7; Pb, 5; Cu, 4.4; Cd, 1.4	
626	Glowray	Similar to Chromel C	
627	Glyco	Pb, 81; Sb, 15; Sn, 4.5; As, 0.5	*557*
628	Glyco metal	Zn, 85.5; Sn, 5; Pb, 4.7; Cu, 2.4; Al, 2	

* As specified by purchaser.

† Climax Molybdenum Co.

* Graded by Si content, S increases as Si decreases.

Index No.	Name	Composition	Page
629	Glyco turbo	Pb, 70; Sb, 22; Sn, 8	
	Gold:		
630	22 carat	Au, 92; Ag, 4.2; Cu, 4.2	
631	22 carat dental, dark	Au, 92; Ag, 4.9; Cu, 3.4	
632	20 carat	Au, 84; Ag, 8.3–11; Cu, 6–8.3	
633	18 carat	Au, 75; Ag, 10–20; Cu, 5–15	
634	16 carat	Au, 67; Cu, 8–27; Ag, 6.6–26	*586*
635	15 carat	Au, 62; Cu, 13; Ag, 11	
636	14 carat	Au, 58; Cu, 14–28; Ag, 4–28	*586*
637	14 carat dental	Au, 58; Ag, 30; Cu, 12	
638	10 carat	Au, 42; Cu, 38–46; Ag, 12–20	*586*
639	8 carat	Cu, 47; Au, 33; Ag, 20	*586*
	Gold solder:		
640	18 carat	Au, 75–63; Ag, 13–31; Cu, 6.3–12	
641	16 carat	Au, 75; Ag, 17; Cu, 8.3	
642	14 carat	Au, 50; Ag, 33; Cu, 17	
643	12 carat	Au, 50; Cu, 35; Ag, 15	*586*
644	10 carat	Au, 41; Ag, 37; Cu, 21; Brass, 0.6	
645	8 carat	Au, 40; Ag, 37; Cu, 23	*586*
646	Best	Au, 63; Ag, 23; Cu, 15	
647	Easy melt	Au, 55; Ag, 32; Cu, 14	
648	Very easy melt	Ag, 55; Cu, 29; Au, 12; Zn, 5.5	
649	Goldal	A dental alloy	
650	Gold imitation (DRP 47 380)	Cu, 97.8; Al, 2; Au, 0.2	
651	Gold leaf metal	Cu, 84–66; Zn, 16–34; Pb, 0–0.4	*469, 555*
	Government (U. S.) bronze:		
652	Spec. G	Cu, 88; Sn, 10; Zn, 2	565, 572
653	Spec. H	Cu, 83; Sn, 14; Zn, 3; Pb, 0.8	
654	Substitute	Cu, 90; Sn, 6.5; Zn, 3; Pb, 0.5	*565*
655	Graney bronze	*v.* Gurney's bronze	
656	Granfin (cast iron)	Fe; C, 2.2–2.6; Graphite, 1.7–2.1; Si, 2.3–2.5; Mn, 0.7–1; P, 0.45–0.6; S, 0.3	*497, 527,* 600, 608
657	Graphalloy	Graphite bearing-metal	
658	Graphite metal	Pb, 80; Sb, 20	*475, 557*
659	Graphite metal	Pb, 68; Sb, 17; Sn, 15	*557*
660	Green gold	Au, 75; Ag, 11–25; Cd, 13–0	
661	Grey cast iron	Fe; C, 2.5–4; Si, 1.3–2; Mn; P; S (fracture is gray due to free graphite)	464, 476, 497, 526, 600, 608
662	Grey gold	Au, 86; Fe, 5.7–17; Ag, 0–8.6	
663	Guillaume's metal	Cu, 64.3; Bi, 35.7 (name also applied to Invar type)	
	Guishibuichi	*v.* Shibu-ichi	
664	Gun metal	Cu, 95–71; Sn, 0–11; Pb, 0–13; Zn, 0–5; Fe, 0–1.4	476, 559–572, 601
665	Gun mount bronze	Cu, 80; Zn, 17; Sn, 3	
666	Gurley's metal	Cu, 86.5; Zn, 5.4; Sn, 5.4; Pb, 2.7	
	For B. E. S. A. Specifications	*v.* p. 386	
667	Gurney's bronze (Graney?)	Cu, 76; Zn, 15; Sn, 9	
668	Guthrie's alloy	Bi, 47; Sn, 20; Pb, 19; Cd, 13	
669	Halberland alloy	Cu, 87; Zn, 13	*469, 555*
670	Half hard steel (Key No. 30, p. 495)	Fe; C, 0.49; Si, 0.44; Mn, 0.34; P, 0.06; S, 0.04	470, 491, 495
671	H. A. L. H. steel	Similar to Stellite	
672	Hamilton metal	Zn, 93; Cu, 3.5; Pb, 3.1; Sb, 1.5; P-Sn, 5 (name also applied to Chrysorin)	
673	Hammonia metal	Sn, 65; Zn, 32; Cu, 3.3	
674	Hard aluminum	Al, 77; Zn, 12; Mg, 4.5 (*v. also* Index No. 682)	
675	Hard babbitt	Sn, 83; Cu, 8.4; Sb, 8.3	
676	Hard bearing	Pb, 98.7; Mg, 1.3 (U. S. patent 803 920)	*556*
677	Hard drawing brass	Cu, 62–59; Zn, 38; Pb, 0.06–3.4	*469, 555, 601*
678	Hard head	Sn, 90; Sb, 8; Cu, 2	*476, 556*
679	Hardite	Ni, 45; Cr, 15; Fe, 13; Sb, 10.6; Cu, 6; Zr, 4; Mo, 3.5; Mn, 2; Al, 0.9	
680	Hard lead	Pb-Sb; Pb-As; Pb-alkali metal or Pb-alkaline earth metal	475, 476, 556, 557
681	Hard phosphor bronze	Cu, 93; Sn, 7; P, 0.2	*560, 601*
682	Hard sheet aluminum	Al, 99–98; Mn, 1–2	*468, 542*
683	Hardware bronze	Cu, 88; Zn, 9.5–12; Sn, 0–1.5; Pb, 0–1	*469, 555*
684	Hard zinc (Hartzink)	Zn, 92; Fe, 5.3; Pb, 2.4; Cu, 0.1	
685	Harlington (Harrington?) bronze	Cu, 56; Zn, 43; Sn, 0.9; Fe, 0.6	*470, 556*
686	Harmonia bronze	Cu, 57–55; Zn, 40–41; Fe, 1.3–1.8; Pb, 0.4; Al; Sn	*556*
687	Haynes metal, soft	Co, 62; W, 28; Cr, 10	
688	Haynes metal, hard	Co, 45; W, 40; Cr, 15	
689	Haynes metal	Fe, 75–70; Cr, 20–30; Co, 5–25	
	Heat resistant alloys	For list, *v.* p. 391	
690	Heat resistant steel (U. S. patent 1 357 549)	Fe, 70; Cr, 15; Co, 14; Mn, 0.5; Si, 0.5; C, 0.5	
691	Heavy axle bearing	Zn, 47; Sn, 38; Sb, 6; Pb, 4; Cu, 1	
692	Heavy bearing	Sn, 85; Cu, 7.5; Sb, 7.5	
693	Helmet metal (helmet bronze)	Cu, 72–70; Zn, 28–30	*555, 601*
694	Hercules bronze	Cu, 86; Sn, 10; Al, 2.5; Zn, 2	
695	Hercules metal	Cu, 54; Zn, 36; Fe, 7.5; Al, 2.5	
696	Heusler's magnetic alloys	Cu, 70–61; Mn, 18–30; Al, 8–15; Pb, 4–0	
697	Most magnetic	Cu, 61; Mn, 26; Al, 13	
698	High carbon steel	Fe; C, 0.65–1.55; Mn; Si; P; S	492, 493, 600–608
	High manganese bronze	*v.* Index Nos. 430, 842	
699	High manganese nickel	Ni, 98–94; Mn, 2–6	473, 482
	High speed steel:		
700	Brit. patent 139 837	Fe; Mo, 6; Co, 6; Cr, 4; C, 0.6	
701	Brit. patent 144 326	Fe; Mo, 6–10; Cr, 3–6; Co, 0.5–2; U, 0.2–1; Mn, 0.2–0.4; Si, 0.2–0.4; C, 0.5–0.8	
702	U. S. patent 1 337 209	Fe; Mo, 6–10; Cr, 3–6; Mn, 0.2–0.4; Si, 0.2–0.4; C, 0.5–0.8	
703	U. S. patent 1 337 210	Fe; Mo, 3–10; Co, 1–5; V, 0.2; Mn, 1–2; Si, 0.1–0.3; C, 0.6–1.2	
704	High temperature bronze	Cu, 91; Zn, 6.3; Sn, 2.7; Pb, 1.3	
	High tensile brasses	For list, *v.* p. 389	
705	Hohenzollern brass	A high tensile brass	
706	Hooker brass	Cu, 61; Zn, 37; Pb, 2	*469, 602*
707	Hopkinson's alloy	Fe, 75; Ni, 24.5; Si; etc.	*481*
708	Hot rolling brass	*v.* Tube brass	
709	Hoyle's metal	Sn, 46; Pb, 42; Sb, 12	*557*
710	Hoyt metal	Pb, 94–90; Sb, 6–10	*557*
711	Huron metal, cast	Al; Cu, 6.6; Ni, 1.3; Mg, 0.5; Co, 0.3; (Mn + Sn + Cd), 0.5	*536*
712	Huron metal, rolled	Al; Cu, 3.5–4; Mg, 0.5; Mn, 0–0.6; Cr, 0.1–0.6	*534*
713	Husmann metal	Sn, 74; Sb, 11; Pb, 11; Cu, 4; Fe, 0.2; Zn, 0.2	
714	Hydraulic bronze	Cu, 83; Sn, 11; Zn, 6; Pb, 0.1	*476, 565*
715	Hydrone	Pb, 67; Sb, 33	
716	Ia-Ia	Cu, 60; Ni, 40	*464, 480*
717	Ideal, Elalco	Cu, 58–53; Ni, 40–45; Fe, 0.6–1; Mn, 0.5–1; Al	*464, 480, 601, 606*
718	Ignition pin alloy	Ce, 61; Fe, 37	
719	Ignition pin alloy	Ce, 73–70; Zn, 17–24; Fe, 1.6–6; Al, 0–2.4; Mn	
720	Illium	Ni, 63; Cr, 21; Cu, 6.5; Mo, 5; W, 2; Fe, 1; Mn, 1; Al, 1	
721	Immadium bronze	Manganese bronze with Al	
722	Imperial	Cu, 80; Ni, 20	*480*
723	Imperial steel	Fe; W, 6.4; Mn, 2.1; C, 1.6; Si	
724	Ingot iron	Fe, 99.9; C, 0.02; Mn; Si; P; S; *v. also* Armco iron	470, 487, 602, 606
725	Injector bronze	Cu, 84; Sn, 8.5; Zn, 5; Pb, 2.5	*569*
726	Instrument bronze	Cu, 82; Sn, 13; Zn, 5	
727	Invar	Fe, 64; Ni, 36; C, 0.15–0.2	471, 482
728	Iridosmine	*v.* Osmiridium	
	Iron	For lists of ferrous alloys *v.* pp. 390, 391	
729	Iron, electrolytic	Fe; C, <0.03; other impurities, < 0.05	472, 478

Index No.	Name	Composition	Page
730	Ironac	Fe; Si, 13; C, 1.1; Mn; P; S	473
731	Iron bronze	Cu, 82.5; Sn, 8.6; Zn, 4.4; Fe, 4	
732	Ironier's bronze	Cu; Sn; Hg, 1	
733	Iserlohn (cast)	Cu, 64; Zn, 34; Sn, 2.5; Pb, 0.3	556
734	Iserlohn (sheet)	Cu, 70; Zn, 30	555, 601
735	Jacana metal	Pb, 70; Sb, 20; Sn, 10	
736	Jacoby metal	Sn, 85; Sb, 10; Cu, 5	476, 557
737	Jalcase steel	A case hardening steel	
738	Jewelers metal	Cu, 91.5–83; Zn, 6.5–17; Sn, 0–2	469, 555
	Kalchoids	Cu; Sn; Zn, alloy system	
739	Kamarsch bearing alloys	Sn, 85; Sb, 5; Cu, 3.6; Bi, 1.6; Zn, 1.4	
740	Kamarsch bearing alloys	Sn, 71; Cu, 21; Sb, 7.2	
741	Kamarsch bearing alloys	Sn, 71; Sb, 20; Cu, 9.5	
742	Karma	Ni, 80; Cr, 20	480, 608
743	Keene's alloy	Cu, 75; Ni, 16; Sn, 2.8; Zn, 2.3; Co, 2; Fe, 1.5; Al, 0.5	
744	Kienmayer's amalgam	Hg, 50; Sn, 25; Zn, 25	
745	Kelmet	Cu, 70.5–68; Pb, 22.5–25.5; Sn, 6.4–6.6; S, 0.03; Zn, 0.03–0.04; Ni; Fe	562
746	Kemlet	Zn, 67; Al, 15; Cu, 9	546
747	Kern's hydraulic bronze	Cu, 78; Sn, 12; Zn, 10	570, 572
748	K. L. steel (Böhler)	Fe; W, 1.2; Cr, 1.0; C, 0.47	472
749	Kneiss metal	Zn, 50–40; Pb, 25–42; Sn, 25–15; Cu, 0–3	
750	Kochlin's bearing	Cu, 90; Sn, 10	475, 559
751	Koltchak (Koultchoog) aluminium	A Russian alloy similar to duralumin	
752	Kosmos	A dental alloy	
753	Kromax	Ni, 80; Cr, 20	480, 608
754	Kromore	Ni, 85; Cr, 15	467, 480
755	Krupp (Grosmann) bearing	Al, 87; Cu, 8; Sn, 5	
756	Kruppin	Fe; Ni, 28; C	471, 482
757	Krupp type metal	Pb, 60; Sb, 18; Sn, 12; Cu, 4.7; Ni, 4.7; Bi, 1	
758	Krupp V1M steel	Fe; Cr, 14; Ni, 2.3; C, 0.1	
759	Krupp V2A steel	Fe; Cr, 23; Ni, 9.5; C, 0.4	
760	K. S. magnet steel	Fe; Co, 30–40; W, 5–9; Cr, 1.5–3; C, 0.4–0.8	
761	Kuhne's phosphor bronze	Cu, 78; Sn, 11; Pb, 10; P, 0.6; Ni, 0.3	562, 570
762	Kunheim metal	Rare earth metals, 86*; Mg, 12; Al, 2	
763	L-5 alloy	Al, 85; Zn, 13–15; Cu, 2.5–3; Fe; Si	539–542, 537, 601
764	L-8 alloy	Al, 88; Cu, 12; Fe; Si	534, 601
765	L-10 alloy	Al, 89; Cu, 10; Sn, 1; Fe; Si	
766	L-11 alloy	Al; Cu, 6–8; Sn, 0–2; Zn, ≯1; Fe; Si	467, 534, 601
767	Laderig's speculum	Cu, 69; Sn, 29	475, 559
768	Lafond's axle bearing	Cu, 80; Sn, 18; Zn, 2	475, 561
769	Lafond's heavy bearing	Cu, 83; Sn, 15; Zn, 1.5; Pb, 0.5	475, 561
770	Lafond's malleable bronze	Cu, 98; Sn, 1.9	559
771	Lafond's pump bronze	Cu, 88; Sn, 10; Zn, 2	565, 572
772	Lancashire brass	Cu, 73; Zn, 25; Pb, 2	469
773	Latten (Laiton)	Yellow brass	
774	Lautal	Al; Cu, 4; Si, 2; Fe	
775	Law's phosphor bronze	Cu, 89–88; Sn, 9.5–11; P, 0.7–1.0	560, 565, 570–572
776	Lead alloy (for small castings)	Sn, 75; Sb, 20; Pb, 5	
	Lead bronzes	For list, *v.* p. 389	
777	Leaded brass	Cu, 88–62; Zn, 10–35; Pb, 1.7–2.6; Fe	469
778	Leaded bronze	Cu, 88; Zn, 10; Pb, 1.5–1.7; Fe	469
779	Leaded gun metal	Gun metal + 1 % Pb	566, 569
780	Leaded low brass	Cu, 78; Zn, 20; Pb, 1.7; Fe	469
781	Leaded monel metal	Ni, 60; Cu, 32; Pb, 2.2; Fe, 2.2; Mn, 2.0; Si, 0.9; C, 0.2; S	469
782	Leaded screw wire brass	Cu, 69; Zn, 30; Pb, 1.7; Fe	469
783	Lead foil	Pb, 86; Fe, 6.9; Al, 5.5; Sn, 1.9	
784	Lead foil (Calin)	Pb, 87; Sn, 13; Cu, 1	
785	Lead shot	Pb, 99.8; As, 0.2	
786	Lead tape	Pb, 95; Sb, 4.5; Sn, 0.5	557
787	Lechesne (two patents, name usually applied to first composition)	Cu, 90–60; Ni, 10–40; Al, 0.2–0.05	480
788	Ledebur's bearing alloys	Zn, 85; Sb, 10; Cu, 5	
789	Ledebur's bearing alloys	Zn, 77; Sn, 18; Cu, 5.5	
790	Lemarquand's non-oxidizable alloy	Cu, 39; Zn, 37; Sn, 9; Co, 8; Ni, 7	
	Le Mat's metal	*v.* Lutecin	
791	Liberty pistons	Al, 77; Zn, 21; Cu, 1.1; Fe, 0.5; Pb; Sn	538
792	Lichtenberg's alloy	Bi, 50; Pb, 30; Sn, 20	
793	Liddel's alloys	Zn, 90–88; Cu, 6.5–5; Al, 6–5	546
794	Linotype, cheap	Pb, 85; Sb, 11; Sn, 3.5	557
795	Linotype, standard (English)	Pb, 83; Sb, 12; Sn, 5	557
796	Lipowitz alloy	Bi, 50; Pb, 27; Sn, 13; Cd, 10	
797	Little's speculum	Al, 65; Sn, 31; Zn, 2.3; As, 1.9	
798	L M Steel (United Alloy Steel Corp.)	Fe; Ni, 2.8–3.3; Cr, 0.7–0.9; Mo, 0.3–0.5; C, 0.2–0.4; Mn; Si; P; S	472, 605
799	Low brass	Cu, 80; Zn, 20; Pb; Fe	555, 601
800	Low carbon steel	Fe; C, ≯0.25; Mn; Si; P; S	487–491
801	Lowroff phosphor bronze	Cu, 70; Pb, 16; Sn, 13; P, 1	562
802	Lowroff phosphor bronze	Cu, 90; Pb, 5.5; Sn, 4; P, 0.5	561
803	Lucerno	Ni, 68; Cu, 28; Fe, 2.4; Mn, 2.2	469, 480, 600, 608
804	Lucero	Ni, 65; Cu, 30; Mn, 5	604
805	Ludlum	Fe; Cr, 13–17; Si, 1; Mo, 1; C, 0.4	
806	Lumen (bronze)	Zn, 86–85; Cu, 10; Al, 4–5	546
807	Lurgimetall	Pb, 96.5; Ba, 2.8; Ca, 0.4; Na, 0.3	556
808	Lutecin (Le Mat's Paris metal)	Cu, 80; Ni, 16; Zn, 5; Fe, 5; Sn, 2; Co, 1	
809	Lynite, 109	Al, 89; Cu, 12–14; other elements, ≯1	467, 534, 601
810	Lynite, 122	Al, 92; Cu, 9.3–11; other elements, ≯2	467, 534, 601
811	Lynite, 146	Al, 93; Cu, 7–8.5; other elements, ≯1.7	467, 534, 601
812	Lynite, body alloy	Al, 95; Cu, 5	534, 601
813	Lynite, crank case	Al, 90; Cu, 7.8; Zn, 1.5; Fe, 1.3	536
814	Lynite, piston	Al, 95; Cu, 2; Mg, 1.5; Fe, 0.8; Si, 0.2; Mn, 0.01	
815	Lynite, piston	Al, 89; Cu, 11; Mg, 0.5	534
816	Lynux bronze	Cu, 89; Fe, 7.2; Al, 3.8	
	Lyons gold	*v.* Tombac	
817	Machine bronze	Cu, 50; Ni, 25; Sn, 25	
818	Machinery brass	Cu, 83; Zn, 16; Sn, 1	555
	Machine steel	*v.* Low-carbon steel	
819	Mach's alloy	Al, 98; Mg, 2–10	464, 548
820	Mach's speculum	Al, 69; Mg, 31	
821	Macht's yellow metal	Cu, 57; Zn, 43	555, 602
822	Mackenzie metal	Pb, 70–68; Sb, 17–16; Sn, 13–16	
823	Magnalite	Al; Cu, 2–2.6; Mg, 1.2–2; Ni, 0.7–2; Fe; Si; Sn; Zn	601, 608
824	Magnalium (original)	Al, 95–70; Mg, 5–30	464, 548
825	Magnalium, cast	Al, 85; Mg, 15	464
826	Magnalium, cast x	Al, 95; Cu, 1.8; Mg, 1.6; Ni, 1.2	601, 608
827	Magnalium, cast y	Al, 97; Cu, 1.8; Mg, 1.5; Sn and Pb	
828	Magnalium, cast z	Al, 95; Sn, 3.2; Mg, 1.6; Cu, 0.2; Pb, 0.7	
829	Magnalium, sheet	Al, 95; Mg, 5	548, 601
	Magna metal	Same as Electron	
830	Magno, Elalco	Ni, 95; Mn, 5	473, 482
831	Magnolia metal	Pb, 84–78; Sb, 15–16; Sn, 0.6; Bi, 0–0.3	557
832	Magno-nickel	Ni; Mn, 2–6	473, 482
833	Major metal	Al; Cu, 3; Fe, 2; Zn, 0.4; Ni, 0.4, Si; Mg; Mn	
834	Maillechort*	Cu, 67–65; Zn, 13.5; Ni, 13–19; Fe, 0.5–3.2; Sn; Pb	480

* Includes 2 % H.

* French generic name.

Index No.	Name	Composition	Page
835	Malleable casting pig	Fe; C, 3–4; Si, 0.75–1.5; Mn, ≯1; P, 0.2; S, ≯0.05	
	Malleable cast iron:		
836	American "Black Heart"	Fe; C, 2.8–3.5; graphite, Tr.; Si, 0.6–0.8; Mn, <0.4; P, <0.2; S, <0.07	476, 477, 497, 525, 526
837	European "Reamur"	Fe; C, 2.8–3.5; graphite, Tr.; Si, 0.6–0.8; Mn, <0.2; P, <0.2; S, <0.4	476, 477, 497, 525, 526
838	Mallet alloy	Zn, 75; Cu, 25	465, 546
839	Malloydium	Cu, 60; Ni, 23; Zn, 13; Fe, 0.9	480
840	Maluminum	Al, 87; Cu, 6.4; Zn, 4.8; Fe, 1.4; Si, 0.2; Mn, 0.1; Pb, 0.2	
841	Mangaloy	Ni; Fe; Mn	
842	Manganese brass	Cu, 85–54; Zn, 2–40; Mn, 1–25; Fe, 0–2.4; Ni, 0–2.5; Al; Pb	556
843	Manganese bronze	Cu, 86–82; Sn, 6–17; Mn, 0.2–2.7; Zn, 0–5; Pb, 0–3	
844	Mn-Bronze Mn-c (cast)	Cu, 58; Zn, 40; Mn, 2	556
845	Mn-Bronze Mn-r (rolled)	Cu, 59; Zn, 31; Sn, 1; Mn, 0.3. (The last two, like most alloys called Mn bronzes are really Mn brasses.)	556
846	Manganese copper	Cu, 90–56; Mn, 8.7–41; Fe, 0–2.7; Zn, 0–2; Sn; Si; Pb	
847	Manganese copper	Mn, 52; Cu, 29; Fe, 9.7; Al, 6.3	
848	Manganese nickel	Ni, 98.5–95; Mn, 1.5–5; Fe	473, 482
849	No. 473 alloy	Ni, 96; Mn, 4 (Driver Harris)	473, 482
850	No. 484 alloy	Ni, 98.5; Mn, 1.5 (Hoskins)	473, 482
851	Manganese nickel	Cu, 82–52; Mn, 14–31; Ni, 3–16	
852	Manganese nickel brass	Cu, 65–51; Zn, 5–40; Ni, 2–18; Mn, 1.5–20; Al; Fe; Sn; Pb	
853	Manganese nickel silver	Cu, 73–60; Mn, 2.4–20; Ni, 10–17; Sn, 0–10; Zn, 0–8.8	
	Manganese steel:		
854	Brit. patent 131 980 (pearlitic)	Fe; Mn, 1.4–3.5; Si, 0.2–0.3; C, 0.2–0.6; P; S	471, 520–523
855	Hadfield's (austenitic)	Fe; Mn, 11–14; C, 1–1.3; Si, 0.3–0.8; P, 0.05–0.08; S, very low	471, 520–523
856	Manganin	Cu, 53; Zn, 39; Sn, 2.7; Ni, 2.5; Mn, 1.7; Al, 0.2	
857	Manganin	Cu, 70; Mn, 25; Ni, 5	
858	Manganin	Cu, 86–82; Mn, 4–15; Ni, 2–12; Fe	
859	Mangan-Neusilber	Cu, 73–59; Ni, 10–18; Mn, 2.4–20; Zn, 5–20	
860	Manhardts alloy	Al, 83; Sn, 10; Cu, 6.2; P; Mg, 0.1	
861	Mannheim gold	Cu, 89–80; Zn, 7–12; Sn, 0–9.3; P-Sn, 0–5	556, 561, 563, 565
862	Marine babbitt	Pb, 72; Sn, 21; Sb, 7	
863	Markus alloy	Cu; Ni; Zn	
864	Marsh's patent	Ni, 75; Cr, 25	
865	Marties' non-oxidisable alloy	Ni, 35; Zn, 18; Cu, 17; Fe, 10; Sn, 10	
866	Martin steel (hard) (Key No. 48, p. 492)	Fe; C, 0.73; Si, 0.4; Mn; P; S	492, 523, 602
867	Mathesius metal (U. S. P. 1 549 137)	Pb; Ca, 3; other alkaline earth metals, 1–2	556
868	Matrix brass	Cu, 62; Zn, 37; Pb, 1.5	469, 602
869	Matrix metal	v. Index Nos. 794, 795, 910, 1351–1353, 1426–1429	
870	Mayari cast iron	Mayari pig recast by itself or added to gray cast iron	
871	Mayari pig	Fe; Cr, 2.5–3; Ni, 1.3–1.5; C	
872	Mayari steel	Fe; Ni, 1–1.5; Cr, 0.2–0.7; P, low	510, 605–607
873	McAdamite	Al; Zn, 12–18; Cu, 3.1; Mg, 0.2	537, 601

Index No.	Name	Composition	Page
874	McAdams, W. A., alloys	Al, 82; Cu, 12; Cd, 5; Ag, 1	
875		Al, 80; Sn, 8; Cd, 8; Ag, 4	
876		Al, 70; Zn, 22; Sb, 5; Cu, 3	
877		Al, 70; Zn, 26; Cu, 3; Ag, 1	
878		Al, 69; Zn, 23; Cu, 7.7; Ni, 0.6	
879		Al, 60; Zn, 20; Ag, 17; Cu, 5	
880	McFarland and Harder alloys	Ni, 59–29; Cu, 11–55; Cr, 10–43	
881	McKechnie's bronze	Cu, 57; Sn, 41; Zn, 1; Fe, 1; Pb, 0.5	
	McKinney alloys:		
882	Cast	Al, 96; Cu, 2; Mn, 1.5	534
883	Hard forging	Al, 95; Cu, 3; Mn, 2	534
884	Soft forging	Al, 97; Cu, 2; Mn, 1	534
885	McLure alloy	Al, 85; Cu, 8.2; Sn, 5–6; Fe, 0.9; Si, 0.3; Mn, 0.2; Mg; Ni; Zn	
886	Meco	Cu, 50; Ni, 25; Zn, 20; ?, 5	
887	Medal bronze	Cu, 97–92; Sn, 1–8; Zn, 0–2	559, 601
888	Medal metal	Cu, 84; Zn, 16	555
889	Medium steel	Fe; C, 0.30–0.60	489–491
890	Metalline	Co, 35; Cu, 30; Al, 25; Fe, 10	
891	Meteorite	Al, 98–94; P, 1–4; Zn, 1–2	
892	Meteor steel	A nickel steel	
	Mild steel	v. Low carbon steel	
893	Minargent	Cu, 57–46; Ni, 40–32; Pb, 0–22; W, 2.8–0; Al	
894	Minofor	Sn, 69–66; Sb, 18–20; Zn, 9–10; Cu, 3–4	
895	Mira metal	Cu, 75; Pb, 16; Sb, 6.8; Sn, 0.9; Zn, 0.6; Fe, 0.4; Co; Ni, 0.2	
896	Misch metal	Ce, 60–50; La, 25; (Dy, Sa, etc.), 15; Fe, 1–2	
897	Misco metal	Fe, 57.5; Ni, 25; Cr, 15; Si, 1.5; Mn, 0.5; C, 0.5	604
898	Mitis iron*	Fe; C; Al, 0.06–0.27	529
899	M-M-M (modified monel metal)	Ni, 65–60; Cu, 24–27; Sn, 9–11; (Fe + Mn + Si), 1–3	
900	Mo-1 Steel†	Fe; Cr, 0.7–1; Mo, 0.25–1; C, 0.15–0.23; Mn, 0.4–0.7; Si, 0.1–0.2	472, 605
901	Mo-2 Steel†	Fe; Cr, 0.8–1.1; Mo, 0.25–1; C, 0.23–0.3; Mn, 0.5–0.8; Si, 0.1–0.2	472, 605
902	Mo-3 Steel†	Fe; Cr, 0.8–1.1; Mo, 0.25–1; C, 0.3–0.4; Mn, 0.5–0.8; Si, 0.1–0.2	472, 605
903	Mock gold	Cu, 80–67; Pt, 20–29; Zn, 0–4	
904	Mock gold	Ni, 6; Pt, 1; Ag, 1; Brass, 1	
905	Mock silver	Al, 84; Sn, 10; Cu, 5.5; P, 0.1	
	Modified Monel metal	v. M-M-M	
	Modified "Y" alloy	v. Index No. 1491	
906	Molybdenum steel	Fe; Mo, 0.3–3; C, 0.1–0.45; Mn, 0.6–1.3; Si, 0.3–0.5	472, 605
907	Mond 70	Ni, 70; Cu, 26; Mn, 4	480, 604
908	Monel metal (cast)	Ni, 68; Cu, 28; Fe, 1.9; Si, 1.1; Mn, 0.3; C, 0.18; S	408, 469
909	Monel metal (rods)	Ni, 68; Cu, 28; Fe, 2.0; Si, 0.2; Mn, 1.8; C, 0.26; S	408, 469, 604, 606
910	Monotype, standard	Pb, 74; Sb, 18; Sn, 8	
911	Montanium	Al; Cu, 2.5–3.5; Mg, 0.5	534, 601
912	Morin's Chinese bronze	Cu, 83; Pb, 10; Sn, 5; Zn, 2	561
913	Mosaic gold (Ormulu)	Cu, 63; Zn, 35	555, 601
914	Mousset's silver	Cu, 60; Ag, 28; Zn, 10; Ni, 3.5	
915	MS Steel (Climax Molybdenum Co.).	Fe; Cr, 0.8–1.1; Mo, 0.3–0.4; Mn, 0.6–0.9; C, 0.4–0.6	472, 605
916	Mudge's speculum	Cu, 69; Sn, 31	559, 561
917	Mumetal	Ni, 74; Fe, 20; Cu, 5.3; Mn, 0.7	
918	Muntz metal	Cu, 60; Zn, 40	555, 600
919	Muntz patents	Cu, 63–56; Zn, 37–42; Pb, 0–4	555, 602
920	Murman's alloy	Al, 72; Zn, 15; Mg, 14	

* Wrought iron, melted, deoxidized with Al and cast with or without adding C.
† Climax Molybdenum Co. Made in three Mo-range classes: A: Mo, 0.25–0.4; B: Mo, 0.5–0.75; C: Mo, 0.75–1.

Index No.	Name	Composition	Page
921	Murman's alloy	Al, 92; Zn, 4.4; Mg, 3.6	
922	Mushet steel	Fe; W, 6–8.2; Mn, 0.2–2.6; Si, 0.1–1.6; C, 2.0–2.3	
923	M. W. metal	Similar to Electron	
924	Mystic metal	Pb, 89; Sn, 11; Bi, 0.1	
925	Naval aluminum	Al; Cu, 1.5; Mn, 0.9; Ni, 0.4; Fe; Si	
926	Naval brass	Cu, 66–59; Zn, 32–40; Sn, 1.2–0.5; Fe; Pb (*v. also* Tobin bronze)	470, 556, 602
927	Naval brass, N-c	Cu, 61; Zn, 38; Sn, 1	*556, 602*
928	Naval bronze, No. 4	Pb, 44; Sn, 36; Sb, 16; Cu, 4	
	Naval journal bearing:		
929	Spec. H	Cu, 83; Sn, 14; Zn, 3.5	
930	Spec. HX	Cu, 83; Sn, 14; Pb, 3.5	*561*
	Naval phosphor bronze:		
931	P-c (cast)	Cu, 88; Sn, 8; Zn, 2.5; P, 0.5	*563*
932	P-r (rolled)	Cu, 95; Sn, 4.5; P, 0.5	*560, 601*
933	Naval valve bronze, M	Cu, 87; Sn, 7; Zn, 6	*565*
934	Navy aluminum bronze	Cu, 87–85; Al, 7–9; Fe, 2.5–4.5	*578, 601, 606*
935	Navy bearing	Sn, 91–80; Sb, 4.5–15; Cu, 3.7–5	*557*
936	Needle metal	Cu, 85; Sn, 8; Zn, 5.3; Pb, 1.7	*565*
937	Neogen	Cu, 58; Zn, 27; Ni, 12; Sn, 2; Al, 0.5; Bi, 0.5	
938	Nergandin	Cu, 70; Zn, 28; Pb, 2	*469*
939	Neusilber	Nickel silver	
940	Nevada silver	Nickel silver	
941	Nevastain	Fe; Cr, 9.5; Si, 3.8; C, 0.4	
942	New capital steel	Fe; W, 14; Cr, 3.7; V, 0.1; C, 0.6; Mn; Si; P; S	472
943	Newloy	Cu, 64; Ni, 35; Sn, 1	
944	Newton's alloy (fusible)	Bi, 50; Sn, 19; Pb, 31	
945	N. G. F. alloy (U. S. Naval gun factory).	Al; Cu, 1–1.5; Mn, 0.75–2; Fe, ≯0.5; Si, ≯0.1	*534*
946	Nichroloy I	Ni, 75; Cr, 16; Fe, 8; Mn, 3	
947	Nichroloy II	Fe, 50; Ni, 40; Cr, 7; Mn, 3 (Index Nos. 946 and 947 for wire or ribbon)	
948	Nichroloy (cast)	Fe, 50; Ni, 23; Cr, 20; Mn, 1; C, 1; V, 1; Si; Al	
949	Nichrome	Ni, 80–54; Cr, 10–22; Fe, 4.8–27; Cu, 0–11; Mn, 0–2; C; Si; Ti; Mo	467
950	Nichrome I	Ni, 60; Fe, 25; Cr, 11; Mn, 4	*480*
951	Nichrome II (wire or ribbon)	Ni, 75; Fe, 12; Cr, 11; Mn, 2	
952	Nichrome II (cast)	Ni, 67–65; Cr, 20–22; Fe, 12–14; Mn, 1.5–2	
953	Nichrome III	Ni, 85; Cr, 15	*467, 480*
954	Nichrome IV	Ni, 80; Cr, 20	*480, 608*
955	Ni-chro-zink	A die-casting alloy	

Index No.	Nickel (commercial):	% Ni + Co	Cu (hundredths of %)	C	Fe	Si	S	Page
956	Electrolytic	99.80	4	Tr.	15	0	Tr.	473, 480, 482, 600, 604, 606
957	Ingot or pig	99.20	30 Mn	3	45	3	3.5	
958	Malleable (INCO)	99.00	15	15	55	10	2.5	
959	Malleable B (INCO)	98.75	175	15	50	20	2.5	
960	Malleable C (INCO)	96.75	175 Cu	15	75	20	3	
961	Reduced Ni (INCO)	97.80	26					
	Shot:							
962	X (alloying)	99.15	18	12	38	10	2.5	
	A (for anodes)	98.75	18	45	38	22	2.5	
	F	91.75	20	30	185	575	2.5	

Index No.	Name	Composition	Page
	D nickel	*v.* Magno-nickel	
	Nickel-aluminum	*v.* Aluminum-nickel	
963	Nickel-aluminum bronze	Cu, 88; Ni, 10; Al, 2	
964	Nickel-aluminum bronze	Ni, 40; Al, 30; Sn, 20; Cu, 10	
965	Nickel bearing	Cu, 50; Ni, 25; Sn, 25	
966	Nickel brass	Cu, 50–54; Zn, 35–44; Ni, 1.5–15; Al; Fe	
967	Nickel boron steel	Fe; Ni, 2.8–3.6; B, 0.1–0.5; C, 0.15–0.7; Mn; Si; Al	530
968	Nickel bronze	Cu, 62–47; Ni, 12–31; Zn, 11–21; Pb, 0–18; Sn, 1–8; Bi, 0–0.1	
969	Nickel bronze	Cu, 47; Sn, 10; Ni, 3; P-Sn, 1.0	
970	Nickel cerium steel	Fe; Ni, 2.2–3; Ce, 0.1–0.9; C, 0.4–0.75; Mn; Si	531, 605
971	Nickel-chrome, superior	Ni; Cr, 19.5; Fe, 0.5; Mn, 2; C, 0.2	*480*
972	Nickel-chrome, peerless	Ni; Cr, 16.5; Fe, 3.0; Mn, 2; C, 0.1	*480*
973	Nickel-chrome, premier	Ni; Fe, 25; Cr, 11; Mn, 3	*480*
	Nickel-chromium steel	*v.* Chrome-nickel steel	
974	Nickel-chromium cast iron	Fe; C, 3–4; Ni, 0.4–5; Cr, 0–0.5; Si; Mn; P; S	
975	Nickel coinage* (U. S. A.)	Cu, 75; Ni, 25	*480*
976	Nickel-copper steel	Fe; Ni, 1–25; Cu, 0.4–10; C, 0.15–0.8; Mn; Si; P; S	513
977	Nickelene	Cu, 55; Zn, 21; Ni, 13; Pb, 10; Sn, 2	
978	Nickeline	Cu, 75–55; Ni, 18–32; Zn, 0–20; Fe; Pb	*475, 480, 601, 606*
979	Nickel-manganese bronze	Cu, 53; Zn, 39; Sn, 2.6; Ni, 2.5; Mn, 1.7; Al; Pb (*v. also* Index No. 842)	*556*
980	Nickel-molybdenum steel	Fe; Ni, 1.5–3; Mo, 0.1–0.7; C, 0.4; Mn; Si; P; S	604, 605
981	Nickel oreide	Cu, 63–66; Zn, 31–33; Ni, 2–6	
982	Nickel oreide	Cu, 87; Ni, 6.7; Zn, 6.7	
983	Nickeloy	Al, 94; Cu, 4.2; Ni, 1.4	*534*
984	Nickel-silicon steel	Fe; Ni, 2.8–3.3; Si, 0.5–2.2; C, 0.35–0.5; Mn; P; S; Al	472, 605
	Nickel silver:		
985	10 %	Cu, 65–56; Zn, 25–34; Ni, 10	480, 601
986	14 %	Cu, 60–56; Zn, 26–28; Ni, 14	480
987	15 %	Cu, 64–57; Zn, 21–28; Ni, 15	*475*, 480
988	18 %	Cu, 65–55; Zn, 17–27; Ni, 18	*475*, 480
989	20 %	Cu, 64–53; Zn, 16–27; Ni, 20	*475*, 480
990	25 %	Cu, 55; Ni, 25; Zn, 20	*475*, 480
991	30 %	Cu, 65–47; Zn, 5–23; Ni, 30	*475*, 480
992	Casting	Cu, 70–56; Ni, 13–20; Zn, 5.6–24; Sn, 0–4; Pb, 0–3.5	*475*, 480, 601
993	Cupping, drawing, milling, spinning	Cu, 59–54; Zn, 22–31; Ni, 12–20; Pb, 0–1	*480*
994	Rolling	Cu, 49; Zn, 39; Ni, 12	*480*
995	Turning	Cu, 65–59; Zn, 22–29; Ni, 12; Pb, 0–5	*480*
	Nickel steel:		
996	Austenitic, above	Ni, 29; C, 0 to Ni, 0; C, 1.65	471, 481, 482, 600–608
997	Martensitic, between	Ni, 29; C, 0 to Ni, 0; C, 1.65 Ni, 13; C, 0 to Ni, 0; C, 1.65	
998	Pearlitic, between	Ni, 13; C, 0 to Ni, 0; C, 1.65 Ni, 0; C, 0 to Ni, 0; C, 1.65	
999	Cementitic	C, > 1.65	
1000	Brit. patent 133 069	Fe; Ni, 2.8; Mn, 0.9; Cr, 0.4; Mo, 0.3; Si, 0.3; Ti, 0.1; C, 0.2	
1001	Carpenter high Ni	Fe; Ni, 23–30	*471, 482*
1002	Nickel-tungsten	W, 75–50; Ni, 25–50	
1003	Nickel-uranium steel	Fe; Ni, 0.3–0.4; U, 0.2–0.4; C, 0.2–0.8	478
1004	Nickel-vanadium steel	Fe; Ni, 3–3.3; V, 0.1–0.45; C, 0, 36; Si, 2.4; Mn; P; S	513, 605
1005	Nickel-zirconium	Ni, 86; Si, 6; Zr, 1.5; C, 0.1	
1006	Nickel-zirconium steel	Fe; Ni, 3; Zr, 0.24; C, 0.4; Si, .2.4; Mn; P; S	532, 605
1007	Ni-Cr-Al	Ni, 88; Al, 12; Cr, 8	
1008	Ni-Cr-Cu	Ni, 85–80; Cr, 20–25; Cu, 15–20	
1009	Nicu steel	Fe; Ni, 2.2; Mn, 0.6; Cu, 0.5; C, 0.3	*513*
1010	NM steel†	Fe; Ni, 3–5; Mo, 0.3–0.7; C, 0.2–0.4; Mn, 0.3–0.5; Si, 0.1–0.2	*605*
1011	Noheet	Pb, 98; Na, 1.4; Sb, 0.11; Sn, 0.1	*556*

* Certain European coins are made of commercially pure Ni.
† Carbon Steel Co. and Climax Molybdenum Co.

Index No.	Name	Composition	Page
1012	Nongran	Cu, 87; Sn, 11; Zn, 2–3; P	565
1013	Non-oxidizable (U. S. patent 1 333 151)	Fe, 62; Cr, 25; Mn, 10; C, 1.1; Si, 0.95	
1014	Non-pareil	Pb, 78; Sb, 17; Sn, 5	557
1015	Novo steel	Fe; W, 19; Cr, 2.9; C, 0.6	472
1016	N. P. L. alloy ("Y" alloy)	Al, 93; Ni, 2; Mg, 1.5	534, 601
1017	Non-shrinking (patent)	Pb, 87; Sb, 6; Sn, 6; Cd, 1.3.	
	Numbered alloys	For the following alloys known by a number (No. 12, No. 193, No. 300, No. 473, No. 484), *v.* Index Nos. 66, 450, 575, 849, 850, respt.	
1018	Nürnberger gold	Cu; Al, 2–7.5; Au, 0.2–2.5	
1019	Oil hardening steel	Fe; Mn, 1.3–1.8; C, 0.8–1; Si, 0.3–0.4	471, 521, 522
1020	Oker (cast)	Cu, 72; Zn, 24; Fe, 2.3; Pb, 1.1	
1021	Oker (sheet)	Cu, 55; Zn, 45; Sn, 0.5	470, 556
1022	Oker I (sheet)	Cu, 69; Zn, 30; Pb, 0.97	469
1023	Onion's alloy	Bi, 50; Pb, 30; Sn, 20	
1024	Optical bronze	Cu, 89; Zn, 6.5; Sn, 4.5	476
1025	Optical wire	Cu, 54; Zn, 28; Ni, 18	480
1026	Oranium bronze H	Cu, 90; Al, 10	575, 601
1027	Oranium bronze M	Cu, 95; Al, 5	574, 600
1028	Oranium bronze MH	Cu, 92; Al, 8	574, 600
1029	Oranium bronze S	Cu, 97; Al, 3	574, 600
1030	Oréide (French gold)	Cu, 90–81; Zn, 10–15; Sn, 0–4.9; Pb	555
1031	Oréide, Brunswick	Cu, 68; Zn, 32; Sn, 0.5	556
1032	Ormulu* (Or moulu)	Cu, 58; Zn, 23; Sn, 17	
1033	Ormulu, large	Cu, 91; Sn, 6.5; Zn, 3	476, 563
1034	Ormulu, small	Cu, 94; Sn, 5.9	559, 601
	Osmiridium (natural):		
1035	Nevyanskite	Ir, 58–44; Os, 27–49; Pt, 0–10; Ru, 0–6; Rh, 1.5–3; Pd; Fe; Cu	
1036	Siserskite	Os, 57; (Rh + Ir), 34; Ru, 8; Pt; Pd; Au; Fe; Cu	
1037	Otto's speculum	Cu, 69; Sn, 32	559, 561
1038	Ounce metal	Cu, 85; Pb, 5; Sn, 5; Zn, 5	561
1039	"P" alloy	Al; Fe, 0.11; Si, 0.11	535, 599
	Packfong	*v.* Paktong	
1040	Packing	Pb, 82; Sn, 4.8 (*v. also* Index No. 56)	467, 557
1041	Packing, piston	Pb, 73–76; Sn, 12–14; Sb, 10–15	
1042	Packing, valve	Sn, 71; Sb, 24; Cu, 5	
1043	Packing, valve rod	Sn, 82; Sb, 10; Cu, 8	
1044	Packing (Russian)	Zn, 99; Sn, 0.9; Pb, 0.3; Fe, 0.2	462, 545, 546
1045	Paktong (Pai t'ung or white copper)	Ni, 41–32; Cu, 26–40; Zn, 16–37; Fe, 0–2.6	480
1046	Palau	Au, 80; Pd, 20	
1047	Palau	Ni, 60; Pt, 20; Pd, 10; V, 10	
1048	Palau	Au; Ir	
1049	Pale yellow gold	Au, 92; Ag, 0–8.3; Fe, 8.3–0	
1050	Palladium alloy	Pd, 90; Rh, 10	
1051	Palladium alloy	Pd, 67; Ag, 33	585
1052	Palladium gold	Au, 90; Pd, 10	
1053	Palladium gold	Cu, 40; Au, 31; Ag, 19; Pd, 10	
1054	Parisian alloy	Cu, 69; Ni, 19.5; Zn, 6.5; Cd, 5	
1055	Paris metal	*v.* Lutecin	
1056	Parker's chrome alloy	Cu, 60; Zn, 20; Ni, 10; Cr, 10	
1057	Parr	Ni, 80; Cr, 15; Cu, 5	
1058	Parr	Ni, 67; Cr, 18; Cu, 8.5; W, 3.3; Al, 2; Mn, 1; Ti, 0.2; B, 0.2	
1059	Parson's manganese bronze	Cu, 60; Zn, 35; Mn, 2–3; Fe, 1.2; Sn, 0.9; Pb, 0.4; Al, 0.2	556
1060	Parson's white brass	Sn, 81–76; Sb, 6–11; Cu, 4.5–5; Pb, 3.5–13	
1061		Sn, 65–60; Zn, 30–35; Cu, 5	
1062	Partinium	Al, 96; Sb, 2.4; W, 0.8; Cu, 0.6; Sn, 0.2	
1063	Partinium	Al, 89; Cu, 7.4; Zn, 1.7; Fe, 1.3; Si, 1.1	

* Also gilded bronze, brass or copper.

Index No.	Name	Composition	Page
1064	Pattern alloy	Al, 90; Cu, 8; Sn, 2	536
1065	Pattern alloy	Pb, 87; Sb, 13	475, 557
	Pearlitic cast iron	*v.* Index Nos. 1071, 1072	
1066	Pen metal	Au, 67; Cu, 25; Ag, 8; *v. also* Index Nos. 410, 411, 1317	586
1067	Pen metal	Cu, 85; Zn, 13; Sn, 2	555
1068	Percit	Similar to Stellite	
1069	Percussion cap brass	Cu, 95; Zn, 5	469, 555
1070	Percy Al bronze	Cu, 90–86; Al, 7.5–13; Pb, 0–2; Mn, 0–1.5	
1071	Perlit cast iron (Perlitguss)	Fe; (C + Si), 3.4–4.6; Mn; P; S*	
1072	Perlit nickel cast iron	Fe; C, 1.7–3; Si, < 1; Ni; Mn; P; S†	
1073	Permalloy	Ni, 78; Fe, 21; Co, 0.4; Mn, 0.2; Cu, 0.1; C, 0.04; S, 0.04; Si, 0.03	
1074	Permanite	A cobalt steel	
1075	Pewter	Sn, 89–74; Pb, 0–20; Sb, 0–7.6; Cu, 0–3.5; Zn	557
1076	Pewter (*v. also* Berthier's alloy)	Sn, 85; Cu, 6.8; Bi, 6; Sb, 1.7	
1077	Pewter, cast gilt	Cu, 65–64; Zn, 32–34; Pb, 0.3–2.9; Sn, 0.2–2.5	556, 600
1078	Pewter, for clock work	Cu, 61–60; Zn, 31–37; Sn, 1.4; Pb, 0.7–0.9	556, 602
1079	Phenix	Fe, 75; Ni, 25	471, 481
1080	Phono-electric wire	Cu, 98.55; Sn, 1.40; Si, 0.05	559
	Phosphor bronze:		
1081	Rolling	Cu, 96; Sn, 4.5; P, 0.1	464, 560, 565, 601
1082	Sheet	Cu, 95; Sn, 4–5; P, 0.5–1.0	
1083	Wire	Cu, 99; Sn, 1.2; P, 0.05 (*v. also* p. 389)	
	For B. E. S. A. Specifications	*v.* p. 386	
1084	Phosphor copper A. S. T. M. Spec. B52-24T	P + Cu, ≮99.75; P, ≮14 (grade A) or ≮10 (grade B); Fe, ≯0.15	
1085	Phosphor tin A. S. T. M. Spec. B51-24T	Sn, 90–95; P, 5–10; P + Sn, ≮99.50; P, ≮3.5	
1086	Pierrot metal, Beugnot	Zn, 83; Cu, 8.3; Sn, 7.6; Sb, 3.5; Pb, 3	
1087	Pinchbeck	Cu, 83–94; Zn, 6.4–17	469, 555
1088	Pin wire brass	Cu, 61; Zn, 39	555, 601
1089	Pioneer metal	Fe; Ni, 35; Cu, 25; Mo, <5; C, 0.2–0.5	
1090	Pirsch's German silver (*v. also* Index No. 198)	Cu, 80–71; Ni, 16–17; Zn, 1–7.5; Sb, 1–2.8; Co, 1–2; Fe, 1–1.5; Al, 0–0.5	
1091	Piston rings, Seraing	Cu, 89; Zn, 9; Sn, 2	555
1092	Piston rings, Stephenson	Cu, 84; Zn, 8.3; Pb, 4.3; Sn, 2.9; Fe, 0.4	
1093	Placet	Ni, 60; Fe, 20; Cr, 15; Mn, 5	
	Plastic bronze	*v.* Ajax plastic bronze (name also generally applied to Cu; Pb; Sn alloys)	
1094	Plastic metal	Sn, 81; Cu, 9.5; Sb, 8.6; Fe, 1.4	
1095	Platalargan	Pt; Al; Ag	
1096	Platine	Zn, 57; Cu, 43	465, 546
1097	Platine-au-titre	Ag, 83–65; Pt, 17–35	474, 588
1098	Platiniridium (natural)	Pt, 55; Ir, 28; Rh, 7; Cu, 3; Fe, 4; Pd; As	
1099	Platinite	Fe, 54–58; Ni, 46–42; C, 0.15	465, 482
1100	Platinoid	Cu, 60; Zn, 24; Ni, 14; W, 1–2	
1101	Platinoid	Cu, 54; Ni, 25; Zn, 20; Fe, 0.5; Mn, 0.2	475, 480
1102	Platinor	Cu, 45; Pt, 18; Brass, 18; Ag, 9; Ni, 9	
1103	Platinum alloy	Ag, 2–5 parts; Pt, 1 part; Cu, ≯1 part	
1104	Platinum gold, almost white	Au, 70; Pt, 30	585
1105		Pt, 58; Ag, 25; Au, 17	
1106	Platinum gold, white	Au, 60; Pt, 40	585
1107	Platinum-iridium	Pt, 100–80; Ir, 0–20	467, 588
1108	Platinum lead	*v.* Birmingham platinum	
1109	Platinum-rhodium for thermocouples	Pt, 100–80; Rh, 0–20	467, 588

* Pearlitic structure produced by using preheated molds according to U. S. P. 1 544 562.

† Sufficient Ni to precipitate graphite according to U. S. P. 1 564 284.

Index No.	Name	Composition	Page
1110	Platinum silver	Ag, 66.7; Pt, 33.3	474, 588
1111	Platinum solder	Ag, 73; Pt, 27	
1112	Platinum substitute (*v. also* Index Nos. 1046–1048, 1177)	Bi, 72; Al, 24; Bi, 3.7; Au, 0.7	
	Platinum substitutes:		
1113	Cooper's	Ag, 70; Pd, 25; Co, 5	
1114	Cooper's	Ag, 70; Pt, 25; Ni, 5	
1115	Electrical	Au, 70; Ag, 25; Ni or Pt, 5	
1116	Electrical	Au, 68; Ag, 25; Pt, 7.5	
1117	Platnam	Ni, 54; Cu, 33; Sn, 13; Fe, 0.5; Al, 0.3	
1118	Platnik	Pt; Ni	
1119	Plow steel	Fe; C, 0.6–0.9; S, 0.03; P, 0.02–0.03; Mn, 0.4–0.5; Si, 0.15–0.17	470, 491, 492, 516, 600, 602
1120	Plumber's white, No. 1	Cu, 54; Zn, 27; Ni, 17; Pb, 2	
1121	Plumber's white, No. 2	Cu, 54; Zn, 25; Ni, 13; Pb, 7; Sn, 1	
1122	Plumber's white, No. 3	Cu, 58; Zn, 25; Ni, 15; Fe, 1; Pb, 1; Mn, 0.3	
1123	Plumbic bronze	Cu, 69; Pb, 26; Mn, 1.7; Sn, 1.5; Fe, 1.2	
1124	Ponsard's high Mn brass	Cu, 75–50; Mn, 20–25; Zn, 2–15; Fe, 0–16	
1125	Popes Island metal*	Cu, 70; Zn, 15; Ni, 14; ?, 1	480
1126	Poro-bronze	Sn, 80; Sb, 13; Cu, 7	476
1127	Poterie d'étain	Sn, 90; Sb, 9; Cu, 1	476
1128	Potingris	Potinjaune plus Pb and Sn	
1129	Potinjaune (French yellow brass)	Cu, 72; Zn, 25; Pb, 2; Sn, 1.2	
1130	Pot metal	Cu, 80–67; Pb, 20–33	567
1131	Potosi silver	Nickel silver	
1132	Presto steel (Carpenter)	Fe; Cr, 1.4; C, 1.1	
1133	Preuss' alloy	Fe; Co, 34; Si, 0.2–1.5; C, 0.04–0.06	
1134	Primer gilding	Cu, 97; Zn, 3; Pb; Fe	469, 555
1135	Prince's metal	Cu, 83–61; Zn, 17–39	555, 601
1136	Prince's metal	Sn, 85; Sb, 15	557
1137	Projectile steel (*v. also* Index No. 1142)	Fe; Cr, 2.4; C, 0.8; Mn, 0.4; Si, 0.2; P; S	507
1138	Promethium	Cu, 67.5–67; Zn, 30; Al, 2.5–3	556
1139	Propeller bushing	Zn, 69; Sn, 19; Sb, 7; Cu, 5	
1140	Propeller bushing	Bronze + Hg	
1141	Proplatinum	Ni, 72; Ag, 24; Bi, 3.7; Au, 0.7	
1142	Protective deck plate	Fe; Ni, 3.5; Cr, 1.5; C, 0.2–0.3	472, 512
1143	Protective (torpedo defense) netting	Fe; Ni, 27.8; C, 0.4	471, 482
1144	Pyros	A heat resisting alloy	
1145	Q-alloy (cast, grade K-1)	Ni, 68; Cr, 20; Si, 2; Al, 1; (Fe, etc.), 10	
1146	Queen's metal	Sn, 73–51; Pb, 8.8–17; Sb, 9–17; Zn, 8.9–13	
1147	Queen's metal	Sn, 89; Sb, 7; Cr, 3.5; Bi, 1	
1148	Queen's metal	Sn, 89–87; Sb, 7–8.5; Cu, 3.5; Zn, 1	
	Rail steel (carbon) A. S. T. M. Spec. A1–24:		
1149	Bessemer	C(0.37–0.55)†; Mn, 0.8–1.1; P, ≯0.1; Si, ≯0.2	470, 491, 516, 600
1150	Open hearth	C(0.5–0.75)†; Mn, 0.6–0.9; P, ≯0.04; Si, ≯0.2	470, 491, 492, 600
	Rail steel (manganese)	*v.* Index No. 855	
1151	Rakel's metal	Cu, 88; Ni, 11; Mn, 1; Zn, 1	
1152	Randolf metal	A dental alloy	
1153	Raymur	Cu; Ni	
1154	Rayo	Ni, 85; Cr, 15	467, 480
1155	Reactal	Ni; Cr	
	Reamur	*v.* Malleable cast iron	
1156	Red brass (*v.* Tombac)	Cu, 89–83; Zn, 5–12; Pb, 3–10; Sn, 2–5	
1157	Red bronze (Rotguss)	Cu, 93–82; Sn, 4–10; (Zn + Pb), 3–10	569
1158	Red gold	Au, 75; Cu, 25	586
1159	Red metal (*v. also* Index No. 56)	Cu, 70; Zn, 20; Pb, 6; Sn, 4	
1160	Red ray	Similar to Chromel B	
1161	Regel-metall	Sn, 83.3; Sb, 11.1; Cu, 5.6	557

* Generic name for a series of French alloys.

† Content increases with weight per unit length.

Index No.	Name	Composition	Page
1162	Regulus of Venus	Cu, 50; Sb, 50	464
1163	Reichs bronze	Cu, 85; Fe, 7.5; Al, 0.6; Mn, 0.5	
1164	Reith's alloy	Cu, 74.5; Sn, 11.6; Pb, 9; Sb, 4.9	
1165	Reostene	Ni; Fe	
1166	Resistance	Cu, 57; Zn, 26; Ni, 18	480
1167	Resistance	Cu, 85; Mn, 12; Fe, 3	
1168	Resistance	Ag, 67; Pt, 33	474, 588
1169	Resistance, high, non-magnetic	Cr, 70; Ni, 30	
1170	Resistance, Lunge	Cu, 87–84; Mn, 12–14; Fe, 1.8–1.9 (for list of resistance alloys *v.* p. 391)	
1171	Resistin (resistance)	Cu, 87–85; Mn, 12; Fe, 1.8–3	
1172	Resistal	Fe; Ni, 22; Cr, 5.5; Si, 1.25 C, 0.15	
1173	Rezistal (U. S. patents 1 420 707 and 1 420 708)	Fe; Ni, 36; Cr, 27.5; Si, 3.25; C, 0.7 (*v. also* Index No. 179)	
1174	Rheotan	Cu, 84; Fe, 12; Zn, 4; Mn, 2	
1175	Rheotan	Cu, 84; Mn, 12; Zn, 4	
1176	Rheotan II	Cu, 53; Ni, 25; Zn, 18; Fe, 5	
1177	Rhotanium	Au, 90–60; Pd, 10–40	
1178	Richards alloy	Zn, 96; Al, 4	465, 546
1179	Richards bronze	Cu, 55; Zn, 42–43; Fe, 1; Al, 2–1	556
1180	Richardson's speculum	Cu, 65; Sn, 30; As, 2; Si, 2; Zn, 0.7	
1181	Rich gold metal	Cu, 90; Zn, 10	555
1182	Rich low brass	Cu, 85; Zn, 15; Pb; Fe	555
1183	Roberts-Austen (purple gold)	Au, 79; Al, 21	
1184	Rod brass	*v.* Index Nos. 603, 604	
1185	Romanium	Al, 97; Ni, 1.8; Cu, 0.3; Sb, 0.3; W, 0.2; Sn, 0.2	
1186	Roma bronze	Cu, 59; Zn, 41; Pb, 0.4; Al, 0.2; Fe	556
1187	Ronia metal	Brass + Co; Mn; P	
1188	Rosein	Ni, 40; Al, 30; Sn, 20; Ag, 10	
1189	Rosenhain and Archbutt alloy (forging)	Al, 72; Zn, 25; Cu, 3	537
1190	Rose's alloy	Bi, 50; Pb, 28; Sn, 22	
1191	Rose's alloy	Bi, 35; Pb, 35; Sn, 30	
1192	Ross' alloy	Cu, 68; Sn, 32	555
	Rotguss	*v.* red bronze	
1193	Rotoxit	Cu; Si (non-corrosive)	
1194	Rübel bronze (Rübel metal)	Cu, 57–55; Zn, 39–40; Fe, 1.5–2; Ni, 1–3; Al, 0.5	556
1195	Rübel bronze	Cu, 39; Fe, 34; Ni, 18; Al, 8.4	
1196	Rübel bronze	Cu, 80; Al, 10; Fe, 4.5; Ni, 4.5; Mn, 1	
	Ruolz alloys (Ruolz silver)	*v.* Argent français	
	Rupert's metal	*v.* Prince's metal	
1197	Rustless sheets	Fe; Cu, ≯0.2; C	470, 509
1198	Rustless steel (Carpenter)	Fe; Cr, 20; Cu, 1; C, 0.3	604, 606
1199	Salge metal (antifriction)	Zn, 86; Sn, 9.9; Cu, 4; Pb, 1.1	
1200	Sallit's speculum	Cu, 65; Sn, 31; Ni, 4	
1201	Samlegierung	Fe; Mn, 13; Si, 10.2; Al, 5.8; C, 2.5; Cu, 0.3	
1202	Sceptre brass	Cu, 62; Zn, 36; Fe, 1.4; Al, 1.1; Pb, 0.07	556
1203	Schomberg alloy	Zn, 87; Sn, 10; Cu, 3	
1204	Schomberg bearing	Zn, 59; Sn, 40; Cu, 0.4; Pb, 0.2; Fe, 0.2	476
1205	Schulz alloy	Zn, 91; Cu, 6; Al, 3	546
1206	Scleron (Aeron)	Al, 98–85; Cu; Ni; Zn; Li; Si; Mn	468, 534, 601, 608
1207	Screw brass	Cu, 78; Zn, 16; Sn, 4.5; Pb, 1.5	
1208	Screw bronze	Cu, 94; Zn, 5; Sn, 1; Pb, 0.5	555
1209	Screw-nut bronze	Cu, 86; Sn, 11; Zn, 2.3	555
1210	Screw wire brass	Cu, 62; Zn, 38	555, 608
1211	Sea water alloy	Fe; Ni, 17; Mn, 5; C; 0.7; Si	
1212	Sea water alloy	Fe; Ni, 24; Cr, 1.2; Mn, 0.6; C, 0.5; Si, 0.4; Co; Cu	512
1213	Sea water bronze	Cu, 45; Ni, 33; Sn, 16; Zn, 5.5; Bi, 1	
1214	Secretan	Cu, 95–91; Al, 9–5; Mg, 1.5; P, 0.5	

Index No.	Name	Composition	Page
1215	Selva metal	A high tensile brass	
1216	Semiplastic bronze	Cu, 79–75; Pb, 13.5–16.5; Sn, 7–9; P; Fe; Sb; Al	*562, 567*
1217	Semi steel	Fe; total C, 3.0–3.5; combined C, 0.5–0.81; Si, 1.4–1.8; Mn; P; S	*464, 476, 497*
1218	Shaku-do (Shakdo)	Cu, 96–94; Au, 3.7–4.2; Ag, 1.6–0.1; Pb; Fe; As	
1219	Sheathing bronze	Cu, 45; Ni, 32.5; Sn, 16; Zn, 5.5; Bi, 1.5	
1220	Sheet brass	Cu, 72–55; Zn, 27–45; Pb, 0–2; Sn, 0–3.3; Fe	469, *556*
1221	Sheet bronze	Cu, 100–90; Zn, 0–10	469, *555*
1222	Sheffield (Ni silver)	Cu, 63–55; Zn, 17–37; Ni, 11–19; Pb, 0–3	*480, 601*
1223	Sheffield, hard alloy	Cu, 46; Ni, 31; Zn, 20	*475, 480*
1224	Shell head brass	Cu, 75; Zn, 25	*555, 601*
1225	Shibu-ichi	Cu, 67–51; Ag, 32–49; Au; Fe	
1226	Ship nail alloy	Sn, 50; Pb, 33; Sb, 17	
1227	Ship nail brass	Cu, 64; Zn, 25; Pb, 8.5; Sn, 2.5	
1228	Sibley alloy	Al, 67; Zn, 33	*468, 536*
1229	Sibley casting alloy	Al, 80; Zn, 20	*468, 536*
1230	Sideraphite	Fe, 63; Ni, 23; Al, 5; Cu, 5; W, 4	
1231	Siemens Halske	Zn, 48; Cd, 47; Sb, 5	
1232	Silchrome	Fe, 64; Ni, 21; Cr, 6.2; Si, 6.1; Mn, 0.8; C, 0.14	
1233	Silchrome wire	Fe; Cr, 18; Si, 3; W, 3; C, 0.3	
1234	Silcrome	Fe; Cr, 3.2–8.3; Si, 3.5; C, 0.4	
1235	Silico-chromium steel	Fe; Cr, 9–12; Si, ≯5; C, ≯1.2	
1236	Silico-manganese brass	Cu; Zn, 40; Mn, 1–2; Fe, 0.2–0.3; Si, 0.05–1	*556*
1237	Silico-manganese steel	Fe; Mn, 0.45–15; Si, 0.4–1.9; C, 0.1–1.0; P; S	472, 525
1238	Silico-spiegel	Fe; Mn, 15–20; Si, 8–15; P, 0.15; S, 0.01; C	
1239	Silicon bronze	Cu, 98–91; Sn, 1.5–9; Si, 0.05	*559*
1240	Silicon-copper A. S. T. M. Spec. B53–24T	Cu; Si, 10–12; Fe, ≯0.75; Al, Sn, Zn, each ≯0.25; Cu + Fe + Si, ≮99.4 (*v. also* Cuprosilicon)	*464*
1241	Silicon-ferro-chrome	Cr, 55–45; Fe, 30–50; Si, 1–17; C, 2.5–7	473
1242	Sillman bronze	Cu, 86.4; Al, 9.7; Fe, 3.9	*578*
1243	Silicon-nickel	Ni, 80–40; Si, 16–18; Fe, 2.5–30	473
1244	Silicon-manganese	Mn, 68; Si, 20; Fe, 11.6; C, 0.7	473
1245	Silicon-steel	Fe; Si, ≯6; C, ≯0.25; Mn; P; S (*v. also* p. 390)	472, 524, 525
1246	Silumin*	Al; Si, 5–14	*543, 601*
1247	Silvel	Cu, 73; Mn, 12; Sn, 12; Fe, 1.8; Pb, 0.5; Al, 0.3	
1248	Silvel	Cu, 68; Zn, 16; Mn, 6.8; Ni, 6.5; Fe, 2.2; Pb, 0.5; Al, 0.1	
1249	Silver (Rupee)	Ag, 92; Cu, 8	*584, 587*
1250	Silver (U. S. coins)	Ag, 90; Cu, 10	*584, 587*
1251	Silver bronze	Cu, 58; Zn, 23; Ni, 16; Pb, 2; Sn, 1	
1252	Silver bronze	Cu, 68; Mn, 18; Zn, 13; Al, 1.3; Si, 0.3	
1253	Silver bronze	Ag, 77; Cu, 23	464, *585*
1254	Silver foil	Sn, 90; Zn, 10	
1255	Silver foil	Sn, 98; Cu, 2.5	*561*
1256	Silver foil	Sn, 91; Zn, 8.3; Pb, 0.4	
1257	Silverine	Cu, 80–71; Ni, 16–17; Zn, 1–8; Sn, 1–2.8; Co, 1–2; Fe, 1–1.5	
1258	Silverite	Nickel silver	
1259	Silver metal	Zn, 67; Ag, 33	
1260	Silveroid	Nickel silver	
	Silver solder:		
1261	Bureau of Standards	Ag, 40; Sn, 40; Cu, 14; Zn, 6	
1262	Common	Ag, 63; Cu, 30; Zn, 7.5	
1263	French	Ag, 66; Cu, 23; Zn, 10	
1264	Hard	Ag, 80; Cu, 13; Zn, 6.8	
1265	Medium	Ag, 75–70; Cu, 20–23; Zn, 5–7.5	

* A German alloy similar to alpax.

Index No.	Name	Composition	Page
1266	Pure silver	Ag, 72; Cu, 28	
1267	Quick	Ag, 63–57; Cu, 21–28; Zn, 10–12; Sn, 3.8–6.2	
1268	Sterling	Ag, 80; Zn, 18; Cu, 2.5	
1269	Similargent	Nickel silver	
1270	Similor	Cu, 89–80; Zn, 9–20; Sn, 0–7	*555*
1271	Sin-chu (Japanese brass)	Cu, 66.5; Zn, 33.4; Fe, 0.1	*469, 555*
1272	S-less steel (Brearly)	Fe; Cr, 13; C, 0.3	*508, 603*
1273	Smitter Lenian	Cu, 72; Ni, 13; Zn, 9.8; Sn, 2.3; Fe, 2; Bi, 1	
1274	S. M. L. alloy (Monel)	Ni, 68; Cu, 28; Fe, 2.5; Mn, 1.5	*469, 480, 604, 606*
1275	S. M. steel (Carpenter)	Fe; Si, 2; Mn, 0.8; C, 0.5–0.6	*525, 604*
1276	Soft gun metal (No. 11 alloy)	Cu, 90; Sn, 6.5; Zn, 2; Pb, 1.5	*566*

Index No.	Solder (A. S. T. M. Spec. B32-31):	Sn	Approx. Pb	Max. Sb	Max. Cu	Page
	Class A, Grade					
1277	0	63	37	0.12	0.08	467, 557
1278	1	50	50	.12	.08	
1279	2	45	55	.12	.08	
1280	3	40	60	.12	.08	
1281	4	37.5	62.5	.12	.08	
1282	5	33	67	.12	.08	
	Class B, Grade					
1283	1	49.25	50	0.75	0.15	*557*
1284	2	43.5	55	1.5	.15	
1285	3	38	60	2	.15	
1286	4	35.5	62.5	2	.15	
1287	5	31	67	2	.15	

Index No.	Name	Composition	Page
		All grades: Zn + Al = 0; other impurities, ≯0.1	
1288, 1289, 1290	Solder, S. A. E. Specs. 1, 2, 3	Practically same as 1, 2, 3, above.	
1291	Solder, S. A. E. Spec. 4	Pb, 75; Sn, 24.5–25.5; Sb, ≯0.12; Cu, ≯0.08	*467*
	Class A	Zn + Al = 0; other impurities, ≯0.1	
	Solder:		
	For B. E. S. A. Specifications	*v.* p. 386	
1292	Bismuth	Sn, 50–20; Pb, 25–40; Bi, 25–40	
1293	Brazing	Zn, 57–45; Cu, 35–45; Ni, 8–10	
1294	Half and half	Pb, 50; Sn, 50	*467, 557*
1295	Hard	Cu, 57–50; Zn, 43–50	*470, 555*
1296	Hard yellow	Cu, 53; Zn, 43; Sn, 1.3; Pb, 0.3	*470, 555*
1297	Plumber's	Pb, 67; Sn, 33	*467, 557*
1298	Readily fusible	Zn, 67; Cu, 33	*465*
1299	Refractory	Cu, 50; Zn, 50	*465, 555*
1300	Soft, nearly white	Zn, 50; Cu, 44; Sn, 3.3; Pb, 1.2	
1301	Tinman's	Sn, 67; Pb, 33	*467, 557*
1302	Very refractory	Cu, 58; Zn, 42	*465, 555*
1303	Very soft, white	Cu, 57; Zn, 28; Sn, 15	
1304	White	Zn, 60; Cu, 40	*465*
	Solders for various metals and alloys, *v.* under their names		
	Sondermessing	Special (alloy or high tensile) brass	
1305	Sorel's alloy	Zn, 80; Cu, 10; Fe, 10	
1307	Spandau alloy (Austrian alloy)	Zn; Cu, 4–6; Al, 2–3.5	*546*
1308	Speculum	Cu, 69–67; Sn, 31–33 (*i.e.*, alloys of the approximate composition Cu_3Sn and known by various names. For other speculum alloys, *v.* p. 391. Other intermetallic compounds as Mg_3Al_2 are often suitable (*v.* equilibrium diagrams).	*561*
1309	Spark plug wire	Ni; Mn, 2–6; Fe; Cu	473, 482
1310	Spelter wire	Cu, 64; Zn, 36; Pb, 0.4; Fe, 0.2	*555*
1311	Spiauter (hard zinc)	Zn, 90; Sb, 8; Cu, 2	
1312	Spiegeleisen (A. S. T. M. Spec. A98–25T):	Fe; Mn, 15–30; C, 5–6; Si, 1; P, 0.15; S, 0.05	

Index No.	Name	Composition	Page
1313	Grade A	Fe; Mn, 19–21; C, 6.5; P, 0.15; S, 0.04; Si; S*	
1314	Grade B	Fe; Mn, 16–19; C, 6.5; P, 0.25; S, 0.05; Si; S*	
1315	Spoon metal	Nickel silver	
1316	Spring brass	Cu, 72–67; Zn, 28–33; Pb, Fe	*555, 601*
1317	Spring gold	Cu, 50; Au, 25; Ag, 25 (*v. also* Index Nos. 410, 1066)	*586*
	Spring steel: A. S. T. M. Spec.		
1319	Carbon, A14–16, grade A	Fe; C, 0.9–1.1; Mn, ≯0.5; P, ≯0.05; S, ≯0.05	470, 492, 602, 608
1320	Special carbon, A68–18	Same, but Si, 0.25–0.50	492, 493
1321	Cr-V, A60–16, grade A	Fe; Cr, 0.8–1.1; V, 0.15; C, 0.45–0.55; Mn, 0.5–0.8; P, ≯0.05† or 0.04;‡ S, ≯0.05	472, 509, 603, 606
1322	Si-Mn, A59–16, grade A	Fe; C, 0.45–0.55; Mn, 0.6–0.8; P, ≯0.05† or 0.045;‡ S, ≯0.045; Si, 1.8–2.1	472, 523, 525, 604
	For B. E. S. A. Specifications	*v.* p. 386	
1323	Stainless iron	Fe; Cr, 12–14; Mn, 0.1; C, 0.1; Si; P; S	508, 603, 606
1324	Stainless steel	Fe; Cr, 11–14; Mn, 0–0.5; C, 0.3–0.5; Si; P; S	471, 508, 600, 603
1325	Stalloy	Fe; Si, *ca.* 2.5; C	
	Standard gold:		
1326	Great Britain	Au, 92; Cu, 8	586, 589
1327	U. S.	Au, 90; Cu, 10	586, 590
1328	Standard phosphor bronze "S" (Pa. R. R.)	Cu, 79.7; Sn, 10; Pb, 9.5; P, ≯0.8	562
1329	Standard silver	Ag, 92.5; Cu, 7.5	584, 589
1330	Standard (cadmium) silver	Ag, 92.5; Cu, 5.75; Cd, 1.75	584
1331	Stanniol	Sn, 96; Pb, 2.4; Cu, 1; Ni, 0.3; Fe, 0.1	
1332	Statuary bronze	Cu, 95–88; Sn, 1.4–10; Zn, 0–9.5; Pb, 0–6; P; Ni	475, 476, 559–572
1333	Steam bronze	Cu, 88; Sn, 8.1; Pb, 2; Zn, 2	*567*
	Steel:	For a list of steels, *v.* p. 390	
	Automotive steels	*v.* pp. 372, 387	
1334	Billets, ingots, etc., of open hearth or electric steel for forging (A. S. T. M. Spec. A17–21)	Classified into types as follows: A: C steel B: Ni steel (Ni, ≯3) C: Cr-Ni steel (Ni, 1–1.5; Cr, 0.45–0.75) D: Cr-Ni steel (Ni, 1.5–2; Cr, 0.9–1.25) E: Cr-Ni steel (Ni, 2.75–3.25; Cr, 0.6–0.95) F: Cr-Ni steel (Ni, ≯3; Cr, ≯1) G: Cr steel (Cr, 0.6–0.9) H: Cr-V steel (Cr, 0.8–1.1; V, 0.15) Specifications also limit impurities in each type Each type subdivided into grades according to carbon content For C steel; grade 1 = C, 0.05–0.15; grade 8 = C, 0.45–0.60 For alloy steels, same range is covered by grades 11 to 17.	
	For B. E. S. A. Specifications	*v.* p. 386	
1335	Castings (A. S. T. M. Spec. A27–24) Grade A	C, ≯0.45; P, ≯0.07† or 0.06‡	470, 487–491
	Commercial bars (A. S. T. M. Spec. A80–24):		
1336	Dead soft (O. H.)§	Fe; C, 0.05–0.12; Mn, ≯0.55; P, ≯0.05; S, ≯0.06	470, 487, 488, 600
1337	Screw (B)§	Fe; C, 0.08–0.16; Mn, 0.6–0.8; P, 0.09–0.13; S, 0.075–0.15	470, 487, 488, 602
1338	Screw (O. H.)§	Fe; C, 0.15–0.25; Mn, 0.6–0.9; P, ≯0.06; S, 0.075–0.15	488, 489, 600, 602

* As specified.
† Acid.
‡ Basic.
§ B = Bessemer; O. H. = Open hearth.

Index No.	Name	Composition	Page
1339	Soft (B)*	Fe; C, ≯0.15; Mn, ≯0.7; P, ≯0.115	470, 487, 600, 602
1340	Soft (O. H.)*	Fe; C, 0.08–0.18; Mn, ≯0.55; P, ≯0.05; S, ≯0.06	470, 487, 600, 602
1341	Welding (B)*	Fe; C, ≯0.12; Mn, ≯0.6; P, ≯0.115; S, ≯0.08	470, 487, 600, 602
		Other grades specified by points of carbon, thus: O. H. 25–40 carbon (1 point = 0.01 %)	
	For B. E. S. A. Specifications	*v.* p. 386	
1342	Steel bronze	Cu; Al, 8.5; Pb, 1–2	
1343	Steel bronze (Stahl bronze) name also applied to Uchatius bronze	Cu, 59–52; Zn, 36–43; Mn, 2.5–3; Fe, 1; Al, 1	*556*
1344	Stellite	Co, 80–55; Cr, 20–35; W, 0–10	468, *593*
1345	Stellite (No. 2)	Co, 56; Cr, 34–40; W, 9.2; C, 1.5–2; Fe, 0–1	468, *593*
1346	Stellite (No. 3)	Co, 55; Cr, 20–23; W, 20–15; Fe, 5–3; C, 1.5–4	*593*
1347	Stellite	Co, 35; Cr, 26; W, 13; Fe, 10; Mo, 10; C, 1.8	*593*
1348	Stellite	Co, 61–45; Mo, 24–40; Cr, 13–15; Fe	*593*
1349	Stellite	Co, 60–55; W, 25; Cr, 15; Mo, 0–5	
1350	Stephenson's alloy	Sn, 31; Fe, 31; Cu, 19; Zn, 19	
1351	Stereotype metal	Pb, 82–70; Sb, 12–23; Sn, 3.2–17	
1352	Stereotype metal	Sn, 60; Pb, 35; Sb, 5	
1353	Stereotype, standard (English)	Pb, 83; Sb, 13; Sn, 4.5	*557*
1354	Sterlin	Cu, 69; Ni, 18; Zn, 13; Pb, 0.8	*480*
1355	Sterline	Cu, 68; Ni, 18; Zn, 13; Fe, 0.8	*480*
1356	Sterro metal	Cu, 60–55; Zn, 38–42; Fe, 1.8–4.7; Sn	556
1357	Sterling metal	Cu, 66; Zn, 33–27; Fe, 0.7; Sn; Pb, 0–2	*556*
1358	Stone bronze	Cu, 58; Zn, 39; Fe, 1.5; Al, 0.8; Mn, 0.5; Sn	*556*
1359	Stone's English gear bronze	Cu, 89; Sn, 11; P	560, 601
1360	Structural steel† (for bridges) A. S. T. M. A7–24	Fe; C; P, ≯0.06‡ or 0.04;§ S, ≯0.05 (tensile properties specified)	
	For B. E. S. A. Specifications	*v.* p. 386	
1361	Structural nickel† steel A. S. T. M. A8–24	Fe; Ni, ≮3.25; C, ≯0.45; Mn, ≯0.7; P, ≯0.05; S, ≯0.05	472, 481, 600, 602, 607
1362	Structural nickel† steel rivets, same spec.	Fe; Ni, ≮3.25; C, ≯0.30; Mn, ≯0.6; P, ≯0.04‡ or 0.03;§ S, ≯0.05	
1363	Structural silicon steel, A. S. T. M. A94–25T	Fe; C, ≯0.40; Si, <0.2; P, ≯0.06‡ or 0.04;§ S, ≯0.05 (ladle analysis)	487–491, 523, 600, 602, 606
1364	Stuffing box alloy	Cu, 61.5; Ni, 15.5; Zn, 11; Pb, 10; Sn, 2	
1365	Suhler white copper	Cu, 40; Ni, 32; Zn, 25; Pb, 2.6	
1366	Sun bronze	Co, 60–40; Cu, 30–50; Al, 10	
1367	Sun bronze	Cu, 95; Al, 5	*574, 600*
1368	Superbronze	Cu, 57–69; Zn, 21–38; Mn, 3–3.2; Fe, 1.3–2; Al, 1.2–5	*556*
1369	Susini	Al; Cu, 1.5–4.5; Mn, 1–8; Zn, 0.5–1.5	*534*
1370	T. metal	Al, 95; Mg, 3.8; Fe, 0.5; Si, 0.5; Cu, 0.1	*464, 542*
1371	Talmi gold	Cu, 90; Zn, 8.9; Au, 0.9 (Au welded on by rolling)	
1372	Talmi gold	Cu, 86; Zn, 12; Sn, 1.1; Fe, 0.3	*556*
1373	Tandem	Pb, 78; Sb, 17; Sn, 5.9	*557*
1374	Tantiron	Fe, 83.5; Si, 15; C, 1	*473*
	Tarnac	*v.* Manganin	
1375	Taylor white	Fe; W, 8.5; Cr, 3; C, 0.75–1	
1376	Tungsten steels	For list *v.* p. 390	

* B = Bessemer; O. H. = Open hearth.
† Must be open hearth.
‡ Acid.
§ Basic.

Index No.	Name	Composition	Page
1377	Telegraph bronze	Cu, 80; Pb, 7.5; Zn, 7.5; Sn, 5	561
1378	Tenax metal	Zn; Al, 4.2–4.6; Cu, 2.2–3; Pb, $\not>$ 1.2; Fe, $\not>$ 0.35	546
1379	Tensilite	Cu, 67–64; Zn, 24–29; Al, 3.1–4.4; Mn, 2.5–3.8; Fe, 0–1.2; Sn	556
1380	Terne metal	Pb, 88; Sn, 18; Sb, 1.8	
1381	Tetmajer Al bronze	Cu, 93–86; Al, 4.6–10; Si, 1–2.7; Fe, 0.7–1	
1382	Therlo	Cu, 85; Mn, 13; Al, 2	
1383	Thermalloy	Fe, 72; Cr, 25; Mn, 2; Ni, 0.1; C, 0.1	
1384	Thermit (bearing)	Pb; Sb, 15; Sn; Ni	
1385	Thoran	W; W_2C	
1386	Three-twenty (3/20)	Al, 77; Zn, 20; Cu, 3	538, 601
1387	Thurston's brass	Cu, 55; Zn, 44.5; Sn, 0.5	470, 556
1388	Tico	Fe, 67; Ni, 30; Mn, 1.1; Cu, 1.1	482
1389	Tiers argent	Al, 66; Ag, 33	
	Tin brass	For list v. p. 389	
1390	Tinfoil	Sn, 88; Pb, 8; Cu, 4; Sb, 0.5	
1391	Tinsel	Sn, 60; Pb, 40	
1392	Tissier's brass	Cu, 97; Zn, 2; As, 0–1; Sn, 0.5–0	
1393	Titan bronze	Cu, 56; Zn, 46; Fe, 0.3; Al, 0.2	556
1394	Titanium steel	Fe; Ti, 0.3–9; C, 0.1–0.8; Mn; Si; P; S	478
1395	Titan metal	v. Promethium	
1396	Tobin bronze (American Brass Co.)	Cu, 60–59; Zn, 38–39; Sn, 2; Pb; Fe	556
1397	Tombac	Cu, 92–82; Zn, 8–18	469, 555
1398	Tombac (common)	Cu, 72; Zn, 28	555, 600
1399	Tombac (French)	Cu, 80; Zn, 17–20; Sn, 0–3	555, 556
1400	Tombac (red Vienna)	Cu, 98; Zn, 2	469, 555
	Tool steel:		
	Carbon	v. High carbon steel	
1401	High speed	Fe; W, 12–14; Cr, 3–4; V, 1.5–2; C, 0.6–0.8 (v. also p. 390)	
1402	Tophet	Ni, 61; Fe, 26; Cr, 10; Mn, 3	480
1403	Torpedo bronze	Cu, 62–59; Zn, bal.; Sn, 0.5–1.5; Pb; Fe	470, 556, 602
1404	Toucas (Toncas?)	Cu, 36; Ni, 29; Fe, Pb, Sn, Sb, Zn, each 7.1	
1405	Tournay's metal	Cu, 82.5; Zn, 17.5	469, 555
1406	Tourun Leonard's metal	Sn, 90; Cu, 10	561
1407	Trabuk metal	Sn, 88; Ni, 5.5; Sb, 5; Bi, 2	
1408	Trojan steel (Carpenter)	Fe; Ni, 2; Cr, 1; C as desired	472, 510
1409	Tube brass	Cu, 70–60; Zn, 30–40; Pb; Fe	469, 555, 600, 602
1410	Tuc-Tur	Cu, 61–59; Zn, 21–29; Ni, 13–18; Fe, 0.3	475, 480
1411	Tula	Ag with a small amount of Cu and Pb	
1412	Tungsten brass	Cu, 60; Zn, 34; Al, 2.8; W, 2; Ni, 0.75; Mn, 0.7; Sn, 0.2	
1413	Tungsten brass	Cu, 60; Zn, 22; Ni, 14; W, 4	
1414	Tungsten filaments	W; ThO_2, 0.5–0.75	462, 592
1415	Tungsten powder (A. S. T. M. Spec. A97–25T)	W, $\not<$95; maximum amounts of other elements; O, 1.0; Si, 0.75; C, 0.5; P, 0.05; S, 0.05; As; Bi; Cu; Sb; Sn, each 0.03	
1416	Tungsten steel	Fe; W, 1.7–2.2; C, 0.3–0.45; Mn; Si; P; S	472
1417	Turbadium bronze	Cu, 48; Zn, 46; Al, 2; Ni, 2; Mn, 1–8; Fe, 1; Sn, 0.5; Pb, 0.1	556
1418	Turbine brass	Cu, 76–67; Zn, 24–32; Pb; Fe	555, 601
1419	Turbine material	Cu, 81–79; Ni, 19–21; Fe, 0.8 max.	480, 601
1420	Turbiston's brass	Cu, 55; Zn, 41; Ni, 2; Al, 1; Fe, 0.8; Mn, 0.2	556
1421	Tutania (cast)	Sn, 92; Sb, 4.7; Cu, 2.5; Pb, 0.3	557
1422	Tutania (cast, plate)	Sn, 91–90; Pb, 8–6; Cu, 0.7–2.7; Zn, 0.3–1.3	557
1423	Tutania (English)	Sn, 80; Sb, 16; Cu, 2.7; Zn, 1.3	
1424	Tutenag	Commercial Zn, incorrectly applied to Paktong, *i.e.*, Ni silver	
1425	Two to one	Cu, 66.7; Zn, 33.3	555, 602
1426	Type metal	Pb, 70; Sb, 18; Sn, 10; Cu, 2	
1427	(Common)	Pb, 60–56; Sn, 10–40; Sb, 4.5–30	
1428	(English, French, German)	Pb, 78–55; Sb, 5–30; Sn, 2–35; Cu, 0–1	
1429	(Standard)	Pb, 58; Sn, 26; Sb, 15; Cu, 1	557
1430	Typewriter metal	Cu, 57; Ni, 20; Zn, 20; Al, 3	
1431	Uchatius (Uchatins?) bronze	Cu, 92; Sn, 8	559, 601
1432	Udylite	Cd plating	
1433	Ulcometal (Frary)	Pb; (Ba + Ca), 1–2	556
1434	Ulcony	Cu, 65; Pb, 35	567
1435	Ultra capital steel	Fe; W, 17; Cr, 3.4; V, 0.1; C, 0.7; Mn; Si; P; S	472
1436	Unmagnetizable watch wheels	Pt, 62.75; Ni, 18; Cu, 18; Cd, 1.25	
1437	Uranium steel	Fe; U, $\not>$ 3; C, 0.2–0.7; Mn; Si; V	479
1438	U. S. N. brass	Cu, 80–78; Zn, 13–16; Sn, 4; Pb, 3; Fe	
	U. S. N. gun bronze	v. Index Nos. 652–654	
1439	U. S. N. valve bronze	Cu, 87; Sn, 7; Zn, 5; Pb, 1	567
1440	Va alloy	Al, 80; Zn, 14; Cu, 5; Fe, 0.7; V, 0.2	
1441	Valve bronze	Cu, 89–85; Sn, 2.5–10; Zn, 0–9; Pb, 0–6; P	563, 565
	Valve steel:		
1442	Brit. patent 131 492	Fe; Si, 5.8; Ti, 1.5; V, 1.5	
1443	Chrome	Fe; Cr, 11–14; C, 0.4–1.2; Si, 0.1–0.2; S; P	470, 508, 603, 606
1444	Chrome	Fe; Cr, 6.3; C, 0.5–1; Si, 0.1–0.3; Mn, 0–0.1; S; P	470, 508
1445	Tungsten	Fe; W, 14; Cr, 3; C, 0.6	472
1446	Very hard (Brit. patent 320 996)	W, 60; Fe, 26; Ti, 5; Cr, 4; C, 3; Ce, 2	
	For B. E. S. A. Specifications	v. p. 386	
1447	Vanadium brass	Cu, 70; Zn, 30; V, 0.5	
1448	Vanadium bronze	Cu, 61; Zn, 39; V, 0.5	
1449	Vanadium steel*	Fe; V, 0.1–14; C, 0.1–1.3; Mn; Si; P; S	472, 514, 604–607
1450	Vanalium	Al; V	
1451	Vaucher's alloy	Zn, 75; Sn, 18; Pb, 4.5; Sb, 2.5	
1452	Verilite	Al, 96; Ni, 1.5; Cr, 1.5; Cu, 1–0; Mn, 0.1	464
1453	Verilite	Al, 96; Cu, 2.5; Fe, 0.7; Si, 0.4; Mn, 0.3	533, 601
1454	Vestalin	Fe; Ni, 28; C	471, 482
1455	Victor bronze	Cu, 59; Zn, 39; Al, 1.5; Fe, 1.0; V, 0.03	556
	Victoria aluminium	v. Partinium	
1456	Victor metal	Cu, 50; Zn, 34; Ni, 15; Fe, 0.3; Al, 0.1	480
1457	Virginia silver	Nickel silver	
1458	VM steel (Crucible Steel Co. of America)	Fe; Cr, 0.7–1; Mo, 0.35–0.85; V, $\not>$ 0.17; Mn, 0.4–0.6	472, 605
1459	Volomit	Similar to Stellite	
1460	Vulcan-hardite	Ni; etc. (v. also Index No. 679)	
1461	"W" Alloy	Al, 82; Cu, 12; Zn, 4.5; W, 1	
1462	W. 0.33	Al, 85; Cu, 14; Mn, 1	534
1463	Wagner's formula	Cu, 51; Zn, 19; Ni, 13	480
1464	Warne's metal	Sn, 37; Ni, 26; Bi, 26; Co, 11	
1465	Watch alloy	Cu, 50; Ni, 47.2; Cd, 2.8	
1466	Watch alloy	Au, 37.5; Cu, 27; Ag, 23; Pd, 12.5	
1467	Watch alloy	Pd, 70; Cu, 25; Ag, 4; Ni, 1	
1468	Watchmakers' alloy	Cu, 59; Zn, 40; Pb, 1.2	
1469	Wegner and Guhr's aluminum	Sn, 80; Zn, 20	
1470	Welch's alloy (dental)	Sn, 52; Ag, 48	585
1471	Wessel's silver	Cu, 66–51; Ni, 19–32; Zn, 12.5–17; Fe, 0–0.5; Ag, 0–2	480

* Amount of V is usually under 0.4 %.

† C all in combined form.

Index No.	Name	Composition	Page
1472	White alloy	Cu, 64.5; Sn, 32; As, 3.5	
1473	White alloy	Cu, 53–49; Zn, 23–25; Ni, 22–25; Fe, 2–2.4	480
1474	White brass	Zn, 66; Cu, 34	465, 546
1475	White brass	Sn, 65; Zn, 32–33; Cu, 3–2; Fe; Pb	
1476	White bronze	Cu, 54; Zn, 42; Ni, 4; (Fe + Al), 0.3	
1477	White cast iron	Fe; C, $\ngtr$ 4; Si, 0.5–0.9; Mn, $\ngtr$ 0.8; P, $\ngtr$ 0.8; S, 0.1–0.25	476, 477, 497, 527
1478	White copper	Cu, 70; Zn, 18; Ni, 12 (v. also Index No. 1045)	480
1479	White gold	Au, 90; Pd, 10	
1480	White gold	Au, 85–75; Ni, 10–8; Zn, 2–9	
1481	White metal	Sn, 53–49; Pb, 33–34; Sb, 11–14; Cu, 2.4–3.3; Zn, 1–0	557
1482	White metal	Pb, 77; Sb, 15; Sn, 5; Cu, 2.3	557
	White metals	Generic name for various Pb-, Sn-, and Zn- base alloys as babbitts, Brittania, etc. Also applied to Al- or Mg- light alloys and nickel silver.	
1483	White nickel brass (S. A. E. Spec. No. 42)	Cu, 64–55; Zn, bal.; Ni, $\nless$18; Fe, $\ngtr$ 0.35; Al, 0; other impurities, $\ngtr$ 0.25	480, 601
1484	Wiegold (dental)	Cu, 68; Zn, 32; Al, 0.3; Pb, 0.3–0.5	469, 556
1485	Wilmott's aluminium	Sn, 86; Bi, 14	
1486	Wire brass	Cu, 72–65; Zn, 27–35; Sn; Pb	469, 555, 601
1487	Wolframium	Al, 98; Sb, 1.4; Sn, 1–0; Cu, 0.4; Fe, 0–0.2; W, 0.04–0.05	
1488	Wood's alloy	Bi, 50; Pb, 25; Sn, 13; Cd, 13	
1489	Wrought iron	Fe; C, 0.03–0.2; Mn; Si; P; S	600, 602
1490	"Y" alloy (casting)	Al, 92.5; Cu, 4; Ni, 2; Mg, 1.5	534–542, 601, 608
1491	"Y" alloy, modified	Same, plus Mn, 0.5; Si, 0.2–0.8	536, 601, 608
1492	Yale bronze	Cu, 92.5–90; Zn, 7.5–8; Sn, 0.5–1.5; Pb, 0.7–1.5	556
1493	Yellow brass (Latten, Laiton)	Cu, 70–60; Zn, 27–40; Pb, 5.3–0; Sn, 0–1; Fe	469, 470, 555, 556
1494	Yellow gold	Au, 53; Ag, 25; Cu, 22	586
	Yellow metal	v. Index Nos. 918, 919	
1495	Zelco	Zn, 73; Al, 15; Cu, 2	546
	Zeppelin alloys:		
1496	(Angles)	Al, 90; Zn, 7.8; Cu, 0.7; Fe, 0.5; Si, 0.4; Mn, 0.3; Sn, 0.1	468, 536, 600
1497	(Braces)	Al, 99; Fe, 0.4; Si, 0.4; Zn, 0.1; Cu, 0.06	459, 533, 599
1498	(Channels)	Al, 89; Zn, 9; Cu, 0.7; Si, 0.5; Mn, 0.5; Fe, 0.4; Sn, 0.2	468, 536, 600
1499	(Rod)	Al, 95; Cu, 4.2; Mn, 0.6; Si, 0.5; Fe, 0.4	534, 535, 601
1500	Zimalium	Al, 94–89; Mg, 3.7–7.1; Zn, 2.8–4.5	
1501	Zimalium	Al, 74; Zn, 15; Mg, 11	
	Zinc, commercial (spelter) Max. Pb	Max. Fe; Max. Cd; Max. Pb + Fe + Cd	
1502	High grade 0.07	0.03; 0.07; 0.10	462, 545, 546
1503	Intermediate 0.20	0.03; 0.50; 0.50	462, 545, 546
1504	Prime Western 1.60	0.08	
	For B. E. S. A. Specifications	v. p. 386	
1505	Zinc babbitt	Zn, 69; Sn, 26; Cu, 5; Sb, 3	
	Zinc bronze	For a list v. p. 389	
1506	Zinc duralumin ("E" alloy)	Al; Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5	538–542
1507	Zinkalium	Al; Mg, 0.8–8.3; Zn, 0.8–8.3	
1508	Zirconium steel	Fe; Zr, 0.1–0.6; C, 0.2–0.6; Mn; Si; P; S	532
1509	Zisium	Al, 83–82; Zn, 15; Cu, 1–3; Sn, 0–1	537, 601
1510	Ziskon	Zn, 75–67; Al, 25–33	468, 546

British Engineering Standards Association Specifications

B. S. S. No.	Description	Composition	Page
	Aluminium Alloys		
2 T 4	Wrought light Al alloy tubes (duralumin)	Al; Cu, 3.5–4.5; Mn, 0.4–0.7; Mg, 0.4–0.7; Fe, $\ngtr$0.5	468, 534, 601
2 L 1	Wrought light Al alloy bar (duralumin)	Same as 2 T 4 above	468, 534, 601
2 L 4	Hard Al sheets	Al, $\nless$98; Fe, $\ngtr$1.0; Si, $\ngtr$1.0; other impurities, $\ngtr$0.25	459, 533, 601
2 L 5	Al alloy castings	Al; Zn, 12.5–14.5; Cu, 2.5–3.0; Fe, $\ngtr$0.8; Si, $\ngtr$0.7; Pb, $\ngtr$0.1	537, 601
2 L 8	12% Cu-Al alloy castings	Al; Cu, 11.0–13.0; Fe, $\ngtr$0.8; Si, $\ngtr$0.7; Zn, $\ngtr$0.1; Pb, $\ngtr$0.1	467, 534, 601
3 L 11	7/1 Al alloy castings	Al; Cu, 6.0–8.0; Sn, $\ngtr$1.0; Fe, $\ngtr$0.8; Si, $\ngtr$0.7; Zn, $\ngtr$0.1; Pb, $\ngtr$0.1	534, 536, 601
L 24	"Y" Al alloy castings	Al; Cu, 3.5–4.5; Ni, 1.8–2.3; Mg, 1.2–1.7; Zn, 0.1; Sn, 0.1; Fe, $\ngtr$0.8; Si, $\ngtr$0.7; Pb, $\ngtr$0.1	534, 536, 601, 608
	Brass		
207	Special brass ingots for castings:		
	Class 1	Zn; Cu, $\nless$54; Pb, $\ngtr$0.5; other metals, $\ngtr$5.0	
	Class 2	Zn; Cu, $\nless$54; Pb, $\ngtr$0.5; other metals, $\ngtr$5.0	
	Class 3	Zn; Cu, $\nless$54; Pb, $\ngtr$0.5; other metals, $\ngtr$8.0	
	Class 4	Zn; Cu, $\nless$50; Pb, $\ngtr$0.5; other metals, $\ngtr$ 10.0	
	Class 5	Zn; Cu, $\nless$50; Pb, $\ngtr$0.5; other metals, $\ngtr$13.0	
218	Brass bars and sections suitable for forgings and drop forgings	Zn; Cu, 58; Pb, $\ngtr$2.0; total impurities, $\ngtr$0.75	470, 555, 602
249	High speed, screwing and turning brass bars	Zn; Cu, 56–60; Pb, 1.75–3.0; total impurities, $\ngtr$0.75	602
250	High tensile brass bars and sections, grades A and B	Zn; Cu, 54–62; other metals, $\ngtr$5.0	470, 556
264	Hot rolled yellow metal plates, sheet and strip	Zn; Cu, $\nless$59; total impurities, $\ngtr$1.0	555, 601, 602
265	Brass sheet and strip	Zn; Cu, $\nless$61; Pb, $\ngtr$0.6; total impurities, $\ngtr$1.0	555, 601
266	Best brass sheet and strip	Zn; Cu, $\nless$65; Pb, $\ngtr$ 0.35; Fe, $\ngtr$ 0.15; total impurities, $\ngtr$ 0.75	555, 601
267	Cartridge brass sheet and strip	Zn; Cu, 68–74; Ni, $\ngtr$0.1; Pb, $\ngtr$0.07; Fe, $\ngtr$0.05; Bi, $\ngtr$0.006; Sn, 0; Sb, 0; other metals, $\ngtr$0.005	469, 555, 601

Brazing Solder

B. S. S. No.	Description	Composition	Page
263	Grade A.........	Zn; Cu, 53–55; Pb, $\ngtr$0.3; Fe, $\ngtr$0.15; Bi, $\ngtr$0.05; Sn, $\ngtr$0.05; As, $\ngtr$0.05; Sb, $\ngtr$0.05; total impurities, $\ngtr$0.5	470, 555
	Grade B.........	Zn; Cu, 49–51; impurities as in grade A above	465, 555

Silver Solder

B. S. S. No.	Description	Composition	Page
206	Grade A.........	Ag, 60.0–62.0; Cu, 27.5–29.5; Zn, 9.0–11.0; impurities, $\ngtr$0.5	
	Grade B.........	Ag, 42.0–44.0; Cu, 36.0–38.0; Zn, 18.5–20.5; impurities, $\ngtr$0.5	

Soft Solder*

B. S. S. No.	Description	Composition	Page
219	Grade A.........	Pb; Sn, 64.0–66.0; Sb, $\ngtr$1.0; As, $\ngtr$0.05; Fe, $\ngtr$0.02	467, 557
	Grade B.........	Pb; Sn, 49.0–51.0; Sb, 2.5–3.0; As, $\ngtr$0.05; Fe, $\ngtr$0.02	557
	Grade C.........	Pb; Sn, 39.0–41.0; Sb, 2.0–2.4; As, $\ngtr$0.05; Fe, $\ngtr$0.02	
	Grade D.........	Pb; Sn, 29.0–31.0; Sb, 1.0–1.7; As, $\ngtr$0.05; Fe, $\ngtr$0.02	
	Grade E.........	Pb; Sn, 94.5–95.5; Sb, $\ngtr$0.50	467
	Grade F.........	Pb; Sn, 49.0–51.0; Sb, $\ngtr$0.50; As, $\ngtr$0.05; Fe, $\ngtr$0.02	467, 557
	Grade G.........	Pb; Sn, 41.0–43.0; Sb, $\ngtr$0.40; As, $\ngtr$0.05; Fe, $\ngtr$0.02	467
	Grade H.........	Pb; Sn, 34.0–36.0; Sb, $\ngtr$0.30; As, $\ngtr$0.05; Fe, $\ngtr$0.02	467, 557
	Grade J.........	Pb; Sn, 29.0–31.0; Sb, $\ngtr$0.30; As, $\ngtr$0.05; Fe, $\ngtr$0.02	467

* All grades contain: ZnO, 0; Al, 0; total impurities, including As and Fe, $\ngtr$0.25.

Gunmetal

B. S. S. No.	Description	Composition	Page
B 2	Gunmetal castings	Cu, $\nless$86; Sn, 10–12; Zn, $\ngtr$2.5; Pb must be 0	476, 565

Phosphor Bronze

B. S. S. No.	Description	Composition	Page
B 8	Phosphor bronze castings for bearings:†		
	For castings....	Cu, 85–89; Sn, 10–13; P, 0.5–1.0	560
	For ingots for making castings	Cu, 85–89; Sn, 10–13; P, 0.8–1.2	560

† Impurities in both classes are: Zn, $\ngtr$0.25; Pb, $\ngtr$0.25; total impurities, $\ngtr$0.75; P to be added in the form of P-Sn or P-Cu.

Aircraft Steels‡

B. S. S. No.	Description	Composition	Page
S 2		Fe	600
S 6		Fe; Mn, 0.40–0.80; C, 0.35–0.45	471, 491
S 11		Fe; Ni, 3.0–3.75; Cr, 0.50–1.00; Mn, 0.45–0.70; C, 0.25–0.35; W, $\ngtr$1.0; Mo, $\ngtr$0.65; V, $\ngtr$0.25	472, 511, 604
S 14		Fe; Mn, 0.60–0.90; C, 0.10–0.18	471, 488
S 15		Fe; Ni, 2.75–3.5; Mn, 0.20–0.60; C, 0.10–0.15; Cr, $\ngtr$0.30	472, 481, 603
S 28		Fe; Ni, 3.75–4.50; Cr, 1.00–1.50; Mn, 0.35–0.60; C, 0.25–0.32; W, $\ngtr$1.0; Mo, $\ngtr$0.65; V, $\ngtr$0.25	472, 512, 604
S 61		Fe; Cr, $\nless$12.0; Si, 0.50; Ni, $\ngtr$1.00; C, $\ngtr$0.15	471, 603
S 62		Fe; Cr, $\nless$12.0; Si, 0.50; C, 0.15–0.35; Ni, $\ngtr$1.00	471, 508
S 65		Fe; Ni, 2.75–3.5; Cr, 1.0–1.4; Mn, 0.35–0.65; C, 0.22–0.28; W, $\ngtr$1.0; Mo, $\ngtr$0.65; V, $\ngtr$0.25	472, 508, 604
S 67		Fe; Ni, 4.6–5.2; C, 0.08–0.14; Mn, $\ngtr$0.35; Cr, $\ngtr$0.1	481, 604
S 68		Fe; W, $\nless$14.0; Cr, $\nless$3.5; C, 0.55–0.70; Mn, $\ngtr$0.40	472
S 69		Fe; Ni, 3.25–3.75; Mn, 0.50–0.80; C, 0.35–0.45; Cr, 0.30	472, 481
S 70		Fe; C, 0.50–0.60; Mn, 0.40–0.75	470, 491
S 71		Fe; Mn, 0.40–0.80; C, 0.25–0.35	471, 489
S 76		Fe; Mn, 0.50–0.80; C, 0.30–0.45; Ni, $\ngtr$1.0; Cr, $\ngtr$0.5	471, 489–491

‡ All steels except S 61, S 62 and S 68 contain Si, 0.30; S, 0.05; P, 0.05.

Automotive Steels

B. S. S. No.	Description	Composition	Page
5005/101	Wrought steels for forging	Fe; Mn, 0.40–1.00; Si, $\ngtr$0.30; C, $\ngtr$0.20; S, $\ngtr$0.07; P, $\ngtr$0.07	471, 488, 602
5005/102		Fe; Ni, 1.50–2.25; Mn, $\ngtr$0.60; Cr, $\ngtr$0.30; Si, $\ngtr$0.30; C, $\ngtr$0.15; S, $\ngtr$0.05; P, $\ngtr$0.05	480, 481
5005/103		Fe; Ni, 2.50–3.5; Mn, 0.20–0.60; Cr, $\ngtr$0.30; Si, $\ngtr$0.30; C, $\ngtr$0.15; S, $\ngtr$0.05; P, $\ngtr$0.05	472, 480, 481, 603
5005/104		Fe; Ni, 4.50–6.0; Mn, $\ngtr$0.40; Cr, $\ngtr$0.30; Si, $\ngtr$0.30; C, $\ngtr$0.15; S, $\ngtr$0.05; P, $\ngtr$0.05	471, 481, 604
5005/201		Fe; Mn, 0.40–0.80; C, 0.15–0.25; Si, $\ngtr$0.30; S, $\ngtr$0.06; P, $\ngtr$0.06	488, 489, 602
5005/202		Fe; Mn, 0.40–0.80; C, 0.25–0.35; Si, $\ngtr$0.30; S, $\ngtr$0.06; P, $\ngtr$0.06	489–491, 602

No. B. S. S.	Description	Composition	Page
		AUTOMOTIVE STEELS.—(*Continued*)	
5005/203		Fe; Mn, 0.40–0.80; C, 0.35–0.45; Ni, ≯1.0; Si, ≯0.30; S, ≯0.06; P, ≯0.06	*471, 491, 600, 602*
5005/204		Fe; Mn, 0.40–0.80; Ni, 0.30–1.0; C, 0.35–0.45; Si, ≯0.30; S, ≯0.06; P, ≯0.06	*481*
5005/301		Fe; S, ≯0.05; P, ≯0.05	
5005/302		Fe; S, ≯0.05; P, ≯0.05	
5005/401		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, ≯0.30; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 481, 600, 603*
5005/402		Fe; Ni, 3.25–3.75; Mn, 0.50–0.80; C, 0.35–0.45; Cr, ≯0.30; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 481, 600, 603*
5005/501		Fe; Ni, 3.00–3.75; Cr, 0.50–1.00; Mn, 0.45–0.70; C, 0.28–0.34; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 511, 512, 604*
5005/502		Fe; Ni, 3.75–4.75; Cr, 1.00–1.50; Mn, 0.35–0.60; C, 0.25–0.35; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 512, 600, 604*
5005/503		Fe; Ni, 1.25–1.75; Cr, 0.75–1.25; Mn, 0.45–0.65; C, 0.35–0.42; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 510, 600, 604*
5005/601		Fe; Cr, 1.00–1.50; Mn, 0.50–0.80; C, 0.35–0.45; Si, ≯0.30; V, ≯0.25; S, ≯0.05; P, ≯0.05	*472, 509, 600, 603*
5028	Castings:		*487–490*
	Grade 1........	Fe; Mn, ≮0.4; S, 0.06; P, 0.05; C, ≯0.30	
	Grade 2	Fe; Mn, ≮0.6; S, 0.08; P, 0.07	
	For cold working:		
5006/105 5006/205–9	Bars and strip...	Fe; Mn, 0.40–0.80; Si, 0.30; C, 0.15–0.20; S, 0.04–0.06; P, 0.04–0.06	*488, 489*
5006/210	Wire...........	Fe; Mn, 0.5–0.9; C, 0.40–0.60; Si, ≯0.20; S, ≯0.05; P, ≯0.05	*491*
		SPRING STEELS§	
5010/218	Laminated springs	Fe; Mn, 0.60–1.0; C, 0.50–0.65; Si, ≯0.50	*491, 602*
5010/219		Fe; C, 0.75–0.90; Mn, 0.35–0.70; Si, ≯0.40	*492, 602*
5010/603		Fe; C, 0.55–0.65; Mn, 0.50–0.80; Cr, 0.45–0.70; Si, ≯0.50	*506*
5010/604		Fe; Cr, 1.00–1.40; Mn, 0.50–0.80; C, 0.45–0.55; Si, ≯0.50	*506, 605*
5010/605		Fe; Cr, 0.80–1.20; Mn, 0.50–0.80; C, 0.45–0.55; V, ≮0.15; Si, ≯0.50	*509, 605*
5010/801		Fe; Si, 1.50–2.0; Mn, 0.60–1.00; C, 0.50–0.60	*523, 604*

§ All these steels contain: S, ≯0.05; P, ≯0.05.

B. S. S. No.	Description	Composition	Page
		STRUCTURAL STEEL FOR BRIDGES	
15		Fe; P, ≯0.08; S, ≯0.06	
		VALVE STEELS	
114/K10		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, ≯0.3; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*481, 600, 603*
114/S19		Fe; Cr, 8.0–12.0; C, 0.40–0.70; Si, 0.30–0.60; Ni, ≯1.00	*508, 600, 603*
5008/403		Fe; Ni, 2.75–3.50; Mn, 0.35–0.75; C, 0.25–0.35; Cr, ≯0.30; Si, ≯0.30; S, ≯0.05; P, ≯0.05	*472, 481, 600, 603*
5008/602		Fe; Cr, 10.0–14.0; Mn, 0.30–0.60; C, 0.30–0.50; Ni, ≯1.00	*471, 508, 603*
5008/603		Fe; Cr, 6.5–8.5; C, 0.50–0.70; Mn, 0.30–0.60; Ni, ≯1.00	*470, 508*
5008/701		Fe; W, ≮14.0; Cr, ≮3.5; C, 0.55–0.70; Mn, ≯0.40	*472*
		ZINC ALLOYS	
220	Fine zinc (or spelter):		*462, 545, 546*
	Grade A.......	Zn, ≮99.95; Cd, ≯0.02; Pb, ≯0.02; Fe, ≯0.01; As, 0; Sb, 0; Al, 0; Sn, 0	
	Grade B.......	Zn, ≮99.90; Pb, ≯0.08; Cd, ≯0.03; Fe, ≯0.01; As, 0; Sb, 0; Al, 0; Sn, 0	
221	Special zinc (or spelter)	Zn, ≮99.50; Cd, ≯0.25; Pb, ≯0.20; Fe, ≯0.05; As + Sb, ≯0.02; Al, 0; Sn, 0	
222	Foundry zinc (or spelter)	Zn, ≮98.50; Pb, ≯1.25; Cd, ≯0.25; Fe, ≯0.07; Sn, ≯0.02; As + Sb, ≯0.02; Al, 0	

TABLES OF ALLOY CLASSES

In these tables most of the alloys listed in the finding index above, are classified according to composition and according to some of their more important uses. If the alloy class contains many alloys it is broken up into sub-classes according to the type formulae of the alloys comprised in it. Thus the class "Cast Light Alloys" is divided into the sub-classes: Al-Cu; Al-Mg; etc., each containing alloys, the first two symbols of whose type formulae are the same.

In these tables the alloys are identified by their index numbers in the finding index.

Light Alloys

(Al- or Mg-base alloys)

CAST LIGHT ALLOYS

Al-Ag: 149, 1389; **Al-Cr**: 361; **Al-Cu**: 13, 24, 28, 43, 44, 46, 47, 66, 73, 74, 76, 87, 88, 89, 91, 92, 94, 95, 96, 98, 99, 100, 110, 163, 199, 432, 473, 594, 595, 711, 755, 764, 765, 766, 774, 809, 810, 811, 813, 814, 815, 823, 826, 827, 833, 840, 874, 882, 885, 945, 983, 1063, 1064, 1206, 1453, 1461, 1462, 1490, 1491; **Al-Mg**: 27, 819, 820, 824,

Ni, 1–10%: 263, 431, 531, 608, 966, 981, 982, 985, 1476; **Ni, 11–20%**: 151, 154, 156, 158, 165, 263, 336, 396, 531, 605, 608, 617, 618, 619, 834, 853, 966, 978, 986, 987, 988, 989, 992, 993, 994, 995, 1025, 1166, 1222, 1410, 1456, 1463, 1478, 1483; **Ni, 21–30%**: 135, 165, 262, 263, 533, 608, 616, 618, 978, 990, 991, 1101; **Ni, 31–40%**: 978, 1045, 1223; **Ni, 41–50%**: 1045.

Special Nickel Silvers

Nickel silver plus additional elements: this class is divided into sub-classes according to added elements

Ag: 59, 1471; **Al**: 111, 1430; **Al-Cr**: 363; **Cd**: 147, 1054; **Co-Ag**: 356; **Cr**: 1056; **Fe**: 152, 153, 155, 157, 175, 176, 177, 178, 839, 1045, 1176, 1355, 1473; **Fe-Pb**: 1122, 1404; **Fe-Si**: 623; **Fe-Sn-Co**: 808, 1055; **Mn**: 136, 138, 852, 859, 1248; **Mn-Sn**: 853, 979; **Pb**: 39, 993, 995, 1120, 1222, 1354, 1365; **Pb-Sn**: 139, 164, 165, 484, 968, 977, 992, 1121, 1251, 1364; **Sb-Co-Fe**: 1090; **Sn-Bi**: 274, 275, 276, 937, 968; **Sn-Co**: 198, 382, 1257; **Sn-Fe-Bi**: 1273; **W**: 1100, 1413.

Lead Base Alloys

As: 785; **Ba**: 602, 807; **Ca**: 186, 332, 390, 867, 1433; **Cd**: 124; **Cu**: 50, 421; **Fe**: 783; **Mg**: 676; **Na**: 1011; **Sb**: 144, 145, 196, 219–221, 225–232, 460, 475, 525, 532, 624, 627, 629, 657, 658, 659, 710, 715, 735, 757, 786, 794, 795, 822, 831, 910, 1014, 1017, 1065, 1351, 1353, 1373, 1384, 1426, 1427, 1428, 1482; **Sn**: 3, 7, 222, 223, 224, 233, 334, 386, 557, 609, 784, 862, 924, 928, 1040, 1041, 1278–1287, 1291, 1294, 1297, 1380, 1427, 1428, 1429.

Tin Base Alloys

Al: 113, 293; **Bi**: 387, 1485; **Cu**: 498, 560, 621, 675, 692, 740, 1076, 1094, 1255, 1406; **Fe**: 1350; **Ni**: 1407, 1464; **P**: 1085; **Pb**: 235, 247, 248, 388, 476, 477, 539, 550, 559, 709, 869, 1045, 1075, 1146, 1226, 1277, 1278, 1292, 1294, 1301, 1331, 1352, 1390, 1391, 1422, 1481; **Sb**: 20, 53, 162, 174, 185, 236, 237, 238, 240, 241, 242, 243, 244, 245, 246, 310, 311, 312, 313, 314, 315, 404, 474, 485, 678, 713, 736, 739, 741, 776, 894, 935, 1042, 1043, 1060, 1126, 1127, 1136, 1147, 1148, 1161, 1421, 1423; **Zn**: 41, 114, 115, 116, 120, 121, 122, 123, 239, 279, 673, 1061, 1254, 1256, 1469, 1475.

Zinc Base Alloys

Ag: 1259; **Al**: 118, 125, 126, 480, 746, 1178, 1378, 1495, 1510; **Cd**: 117, 1231; **Cu**: 41, 159, 249, 269, 272, 482, 483, 523, 597, 598, 672, 793, 806, 838, 1086, 1096, 1108, 1205, 1293, 1298, 1300, 1304, 1305, 1306, 1307, 1474; **Fe**: 684; **Pb**: 749; **Sb**: 505, 625, 788, 1311; **Sn**: 119, 197, 250, 251, 309, 478, 479, 481, 506, 524, 563, 628, 691, 789, 1044, 1139, 1199, 1203, 1204, 1451, 1505.

Alloys Containing the Precious Metals

Silver Alloys

Ag, < 20%: 149, 288, 534, 630–636, 638–641, 643, 660, 662, 874, 875, 877, 879, 904, 1049, 1053, 1066, 1188, 1467, 1471; **Ag, 20–30%**: 160, 161, 410, 534, 634, 636, 637, 640, 646, 660, 914, 1105, 1116, 1141, 1317, 1466, 1494; **Ag, 31–40%**: 161, 411, 534, 640, 642, 644, 645, 647, 1051, 1225, 1259, 1261, 1389; **Ag, 41–50%**: 534, 1225, 1470; **Ag, 51–60%**: 648, 1103, 1267; **Ag, 61–70%**: 1097, 1103, 1110, 1113, 1114, 1168, 1262, 1263, 1267; **Ag, 71–80%**: 1097, 1103, 1111, 1253, 1264, 1265, 1266, 1268; **Ag, 81–90%**: 351, 1097, 1250, 1329; **Ag, 91–100%**: 1249, 1330, 1411.

Gold Alloys

Au, < 20%: 648, 650, 1018, 1105, 1112, 1141, 1218; **Au, 21–30%**: 410, 660, 1317; **Au, 31–40%**: 639, 645, 1053, 1466; **Au, 41–50%**: 462, 638, 642, 643, 644; **Au, 51–60%**: 534, 636, 637, 647, 1106, 1494; **Au, 61–70%**: 534, 634, 635, 640, 646, 1066, 1104, 1115, 1116, 1177; **Au, 71–80%**: 281, 534, 633, 640, 641, 660, 1046, 1158, 1177, 1183, 1480; **Au, 81–90%**: 534, 632, 662, 1052, 1177, 1327, 1479, 1480; **Au, 91–100%**: 630, 631, 1049, 1326.

Alloys Containing Metals of the Platinum Group

Pt, < 20%: 351, 408, 409, 904, 1035, 1102, 1103, 1116; **Pt, 20–30%**: 408, 903, 1047, 1097, 1103, 1104, 1111, 1114; **Pt, 31–40%**: 1097, 1106, 1110, 1168; **Pt, 41–50%**: 411; **Pt, 51–60%**: 1098, 1105; **Pt, 91–100%**: 1107, 1109.

Pd, < 20%: 1047, 1052, 1177, 1466, 1479; **Pd, 20–30%**: 1046, 1113, 1177; **Pd, 31–40%**: 1177; **Pd, 61–70%**: 1051, 1436, 1467; **Pd, 81–90%**: 1050, 1107, 1109.

Ir: 1035, 1036, 1098, 1107.

Rh: 1035, 1036, 1109.

Os: 1035, 1036.

Ru: 1035, 1036.

Irons

Cast Irons and Pig Irons

4, 191, 192, 349, 353, 441, 536, 579, 601, 656, 661, 835–837, 1071, 1217, 1477.

High Silicon Cast Irons

52, 423, 515, 516, 730, 1374.

Alloy Cast Irons

870, 871, 974.

Recarburizers and Steel Mill Alloys

337, 565–569, 571–574, 576–585, 1238, 1239, 1241, 1244, 1312–1314.

Commercially Pure, Ingot and Wrought Irons

170, 346, 724, 729, 1489.

Steels

Carbon Steels

341, 347, 437, 558, 607, 670, 698, 737, 800, 866, 889, 898, 1019, 1119, 1149, 1150, 1319, 1320, 1334–1341, 1360.

Alloy Steels

Classified by alloying elements

Al: 127, 128; **B**: 292; **Ce**: 344; **Co**: 393, 1074, 1133; **Co-W-Cr**: 760; **Cr**: 12, 376, 422, 596, 1132, 1137, 1272, 1323, 1324, 1443, 1444; **Cr-Co**: 502, 690; **Cr-Cu**: 1198; **Cr-Mo**: 360, 371, 805, 900, 901, 902, 915; **Cr-Ni**: 329, 591, 758, 759; **Cr-Si**: 171, 466, 467, 941, 1235; **Cr-Si-W**: 1233; **Cr-U**: 374; **Cr-V**: 375, 1321; **Cu**: 418, 1197; **Mn**: 854, 855, 1019; **Mn-Si**: 1236; **Mo**: 906; **Mo-Co-Cr**: 700; **Mo-Co-V**: 703; **Mo-Cr**: 702; **Mo-Cr-Co-U**: 701; **Mo-V**: 1458; **Ni**: 586, 727, 756, 892, 996–1001, 1099, 1143, 1361, 1362, 1454; **Ni-B**: 967; **Ni-Ce**: 970; **Ni-Cr**: 31, 328, 372, 373, 564, 613, 872, 1142, 1212, 1408; **Ni-Cr-Mo**: 798; **Ni-Cr-Si**: 179, 454, 897, 1172, 1173, 1232; **Ni-Cu**: 976, 1009, 1388; **Ni-Mn**: 1211; **Ni-Mo**: 980, 1010; **Ni-Si**: 984; **Ni-U**: 1003; **Ni-V**: 1004; **Ni-Zr**: 1006; **Si**: 518, 607, 1245, 1325, 1363; **Si-Mn**: 1237, 1275, 1322; **Si-Ti-V**: 1442; **Ti**: 1394; **U**: 1437; **V**: 1449; **W**: 283, 433, 723, 922, 1416; **W-Cr**: 284, 748, 1045, 1375, 1445; **W-Cr-V**: 285, 942, 1401, 1435; **Zr**: 1508.

Other Ferrous Alloys

With or without carbon and including some of the high alloy steels

Electrical Alloys

Alloys having high resistance, or low temperature coefficient of resistance, *v. also* heat resisting alloys

Corrosion Resisting Alloys

Heat Resisting Alloys

[1] Low temperature coefficient of resistance.
[2] Low thermal expansion coefficient.

Fusible Alloys

Pyrophoric Alloys

Stellite and Similar Alloys

Speculums

Dental Alloys

Bearing Alloys

Copper Base

White Metals

Aluminum base

Lead base

Tin base

Zinc base

MEANINGS OF SYMBOLS DENOTING TREATMENTS

NOTE: Treatments are denoted by capital letters, with subscripts to indicate modifications. Thus "R_c" means "cold rolled."

A commonly occurring abbreviation is $t°/m$, where $t°$ is the temperature at which a particular specimen is held for m units of time (minutes unless otherwise specified).

Care must be used in interpreting some of the data. The effect of heat treatment on properties often varies with the size of the specimen; and although sizes of the test specimens are usually given, it is not always clear whether these have been machined before or after the heat treatment. Where known, dimensions of specimens when heat treated are given in the "Treatment" column.

If symbol is enclosed in a square bracket, [ ], treatment is done in mass, *i.e.*, before machining, but dimensions are not specified.

A	Annealed
A	Annealed drastically
A_b	Box annealed
A_c	Close annealed
A_{N_2}	Annealed in nitrogen
A_v	Annealed *in vacuo*
A_2	Re-annealed
B	Blued
C	Cooled
C_a	Cooled in air
C_{CaO}	Cooled in lime
C_f	Cooled in furnace
C_{fo}	Cooled in furnace with door open
C_{gm}	Cooled in gas muffle
C_m	Cooled in muffle
C_o	Cooled in oil
C_q	Cooled quickly
C_r	Cooled at moderate rate
C_s	Cooled slowly
C_t	Cooled in fireclay tube
$Ct_c°/m$	Cooled through critical range at rate of $t°$ per min
C_s	Cooled in sand
CR	Cherry red heat
Crys.	Single crystal
D	Drawn
D_c	Drawn, cold
D_d	Drawn, hard
D_h	Drawn, hot
DA	Drawn, with annealing
Do	The same
Dp	As deposited
DR	Dark red heat
E	Extruded
F	Forged
F_m	Forged on mandrel
G	Cast, or as cast
G_c	Cast, centrifugal
G_{gt}	Cast in glass tube
G_{hm}	Cast in preheated mold
G_m	Cast, chill
$G_{m/2}$	Cast, semi-chill
G_{phm}	Pressure cast in preheated mold
G_s	Cast, sand
Gr	Ground
Gr_w	Ground, wet
H	Hardened
H_a	Hardened, air
H_o	Hardened in oil
$H_{1/2}$	Half-hard

SIGNIFICATION DES SYMBOLES INDIQUANT LES TRAITEMENTS

NOTE: Les traitements sont mentionnés par des lettres majuscules, avec des indices pour indiquer les modifications. Ainsi "R_c" signifie "laminé à froid."

Une abréviation qui se présente souvent est $t°/m$ où $t°$ est la température à laquelle une éprouvette particulière est maintenue pendant m unités de temps (minutes, à moins d'une indication).

Une certaine attention est nécessaire dans l'interprétation de quelques-unes des données. L'effect du traitement thermique sur les propriétés varie souvent avec les dimensions de l'éprouvette; et quoique les dimensions des éprouvettes essayées soient ordinairement données, il n'est pas toujours évident si celles-ci ont été fabriquées avant ou après le traitement thermique. Les dimensions des éprouvettes traitées thermiquement sont données, lorsqu'elles sont connues, dans la colonne "Treatment."

Si le symbole est compris entre crochets [ ], le traitement est fait en masse, c'est-à-dire avant l'usinage, mais les dimensions ne sont pas spécifiées.

A	Recuit
A	Recuit brutalement
A_b	Recuit en boîte
A_c	Recuit en vase clos
A_{N_2}	Recuit dans l'azote
A_v	Recuit dans le vide
A_2	Double recuit
B	Bleui
C	Refroidi
C_a	Refroidi dans l'air
C_{CaO}	Refroidi dans la chaux
C_f	Refroidi dans le four
C_{fo}	Refroidi dans le four, la porte étant ouverte
C_{gm}	Refroidi dans le moufle à gaz
C_m	Refroidi dans le moufle
C_o	Refroidi dans l'huile
C_q	Refroidi rapidement
C_r	Refroidi d'une façon modérée
C_s	Refroidi lentement
C_t	Refroidi dans un tube d'argile réfractaire
$Ct_c°/m$	Refroidi dans l'intervalle critique à raison de $t°$ par minute
C_s	Refroidi dans le sable
CR	Chaleur rouge cerise
Crys.	Cristal unique
D	Étiré
D_c	Étiré à froid
D_d	Étiré dur
D_h	Étiré à chaud
DA	Étiré avec recuit
Do	Le même
Dp	Comme déposé
DR	Chaleur rouge sombre
E	Matricé
F	Forgé
F_m	Forgé sur mandrin
G	Coulé, ou comme coulé
G_c	Coulé, centrifugé
G_{gt}	Coulé en tube de verre
G_{hm}	Coulé en coquille préalablement chauffé
G_m	Coulé, en coquille
$G_{m/2}$	Coulé, demi-coquille
G_{phm}	Coulé sous pression en coquille préalablement chauffé
G_s	Coulé en sable
Gr	Broyé
Gr_w	Broyé, humide
H	Durci

BEDEUTUNG DER DIE BEHANDLUNG ANGEBENDEN ZEICHEN

BEMERKUNG: Die Behandlungen sind durch grosse Buchstaben gekennzeichnet, der Index zeigt dann ihre Modifikation an. Es bedeutet z.B. "R_c" kalt gewalzt.

Eine häufig vorkommende Abkürzung ist $t°/m$, in welcher $t°$ die Temperatur bedeutet bei welcher ein bestimmtes Materialstück m Zeiteinheiten gehalten wurde (Zeit in Minuten, wenn nichts anderes angegeben).

Die Bedeutung einiger Zahlen muss mit Vorsicht gewertet werden. Der Einfluss der Erwärmung auf die Eigenschaft des Materials ändert sich oft mit dessen Ausmessung. Obgleich die letztere meist angegeben ist, ist es nicht immer klar ob die Prüfung vor oder nach der Wärmebehandlung ausgeführt wurde. Wo bekannt, sind die Dimensionen des Materials sobald es in der Hitze behandelt wurde, in der Kolonne unter "Treatment" angegeben.

Ist das Zeichen in einer eckigen Klammer [ ] so bedeutet dies, dass die Behandlung vor der Prüfung ausgeführt wurde, aber die Ausmessung ist nicht näher angegeben.

A	Ausgeglüht
A	Gründlich ausgeglüht
A_b	In Glühkiste geglüht
A_c	Unter Luftabschluss geglüht
A_{N_2}	In Stickstoff geglüht
A_v	In Luftleere geglüht
A_2	Nochmals geglüht
B	Blau angelassen
C	Erkaltet
C_a	An Luft erkaltet
C_{CaO}	In Kalk erkaltet
C_f	Im Ofen erkaltet
C_{fo}	Dito bei geöffneter Tür
C_{gm}	Im Gasmuffelofen erkaltet
C_m	Im Muffelofen erkaltet
C_o	Im Ölbad erkaltet
C_q	Rasch erkaltet
C_r	Verzögert erkaltet (mässig rasch)
C_s	Langsam erkaltet
C_t	Im Chamotterohr erkaltet
$Ct_c°/m$	Erkaltet mit einer Durchlaufgeschwindigkeit durch die kritischen Punkte von $t°$/min
C_s	Erkaltet im Sand
CR	Kirschrotwärme
Crys.	Einzelkristall
D	Gezogen
D_c	Kalt gezogen
D_d	Hart gezogen
D_h	Heiss gezogen
DA	Gezogen mit Ausglühen
Do	Dasgl.
Dp	Wie niedergeschlagen
DR	Dunkelrothitze
E	Ausgestossen
F	Geschmiedet
F_m	Auf dem Dorn geschmiedet
G	Gegossen oder in gegossenem Zustand
G_c	Zentrifugalguss
G_{gt}	In ein Glasrohr gegossen
G_{hm}	In vorgewärmter Gussform vergossen
G_m	Gegossen in Kokille
$G_{m/2}$	Hartguss
G_{phm}	In vorgewärmter Gussform nach dem Pressverfahren vergossen
G_s	In Sand vergossen

SIGNIFICATO DI SIMBOLI INDICANTI TRATTAMENTI

NOTA: I trattamenti sono designati con lettere maiuscole munite di indice in basso per indicare le modificazioni. Così "R_c" significa laminato a freddo.

Una abbreviazione frequente è $t°/m$ dove $t°$ è la temperatura alla quale un dato campione è mantenuto per m unità di tempo (minuti, quando non è diversamente specificato).

Si deve fare attenzione a interpetrare alcuni dati. L'effetto del trattamento termico sulle proprietà spesso varia con le dimensioni del provino; e sebbene le dimensioni siano in genere indicate, non sempre è chiaro se i provini sono stati portati a quelle dimensioni dopo o prima il trattamento termico. In quest'ultimo caso le dimensioni del provino sono riportate nella colonna "Treatment."

Quando il simbolo è racchiuso fra parentesi quadra [ ], il trattamento s'intende fatto sul pezzo prima di lavorarlo, e le dimensioni non sono indicate.

A	Ricotto
A	Ricotto a fondo
A_b	Ricotto in cassetta
A_c	Ricotto in ambiente chiuso
A_{N_2}	Ricotto in azoto
A_v	Ricotto nel vuoto
A_2	Ricotto una seconda volta
B	Rinvenuto in modo da assumere il color blu
C	Raffreddato
C_a	Raffreddato all'aria
C_{CaO}	Raffreddato in calce
C_f	Raffreddato in forno
C_{fo}	Raffreddato in forno con porta aperta
C_{gm}	Raffreddato in muffola a gas
C_m	Raffreddato in muffola
C_o	Raffreddato in olio
C_q	Raffreddato rapidamente
C_r	Raffreddato a velocità moderata
C_s	Raffreddato lentamente
C_t	Raffreddato in tubo di refrattario
$Ct_c°/m$	Raffreddato attraverso l'intervallo critico con una velocità di $t°$ al minuto
C_s	Raffreddato in sabbia
CR	Temperatura del rosso-ciliegia
Crys.	Cristallo singolo
D	Trafilato
D_c	Trafilato a freddo
D_d	Trafilato duro
D_h	Trafilato a caldo
DA	Trafilato con ricottura
Do	Lo stesso
Dp	Come si deposita
DR	Temperatura del rosso-scuro
E	Fatto passare sotto pressione attraverso a una matrice
F	Fucinato
F_m	Fucinato su mandrino
G	Getto
G_c	Getto centrifugato
G_{gt}	Colato in tubo di vetro
G_{hm}	Colato in forma preriscaldata
G_m	Colato in conchiglia
$G_{m/2}$	Colato in semiconchiglia
G_{phm}	Colato sotto pressione in forma preriscaldata
G_s	Colato in sabbia
Gr	Smerigliato
Gr_w	Smerigliato alla mola
H	Temprato
H_a	Temprato in aria
H_o	Temprato in olio

H_{wk}	Hardened, work
Hm	Hammered
J	Tested (at t°C) or (immediately)
J_a	Tested in air
J_{CO_2}	Tested in CO_2
J_{H_2}	Tested in H_2
J_{la}	Tested in liquid air
J_{N_2}	Tested in N_2
K	Carburized
M	Modified
Ml	Melted
Ml_2	Remelted
Ml_v	Melted in vacuo
N	Normalized
N_a	Normalized in air
N_v	Normalized *in vacuo*
Nat	Natural state
O	As received
P	Pickled
P_w	Pickled and washed
Pl	Plate
Pr	Pressed
Q	Quenched
Q_b	Quenched in boiling water
Q_h	Quenched in hot water
Q_i	Quenched in iced brine
Q_{la}	Quenched in liquid air
Q_o	Quenched in oil
Q_w	Quenched in water
Q_{Pb}	Quenched in lead bath
Q_{salt}	Quenched in salt bath
Q_2	Double quenched
R	Rolled
R_c	Rolled, cold
R_d	Rolled, hard
R_h	Rolled hot
R_s	Rolled, soft
S	Soaked
S_h	Soaked in hot bath
Str	Struck (in coin press)
Sv	As for service
Sw	Swaged
Tp	Tempered
Tp_o	Tempered in oil
Tp_2	Retempered
Trt	Heat treated
U	Refined
V	Aged
W	Heated to
W_{gf}	Heated in gas furnace
W_s	Heated slowly
W_2	Reheated
$Wt°/x$	Heated to t°C and held there for x min
$Wt°/x$h	Heated to t°C and held there for x hr
W	White heat
Wk	Worked (Wrought)
Wk_c	Worked, cold
Wk_d	Worked, hard
Wk_h	Worked, hot
Wk_s	Worked, soft
Y	Yellow heat

In addition to the above, the following signs are used to denote position of test specimen in the original ingot, casting, or rolled bar or plate:

‖	Longitudinal
⊥	Transverse

H_a	Durci à l'air
H_o	Durci à l'huile
$H_{1/2}$	Demi dur
H_{wk}	Écroui
Hm	Martelé
J	Essayé à (t°C) ou (immédiatement)
J_a	Essayé dans l'air
J_{CO_2}	Essayé dans CO_2
J_{H_2}	Essayé dans H_2
J_{la}	Essayé dans l'air liquide
J_{N_2}	Essayé dans N_2
K	Carburé
M	Modifié
Ml	Fondu
Ml_2	Refondu
Ml_v	Fondu dans le vide
N	Normalisé
N_a	Normalisé dans l'air
N_v	Normalisé dans le vide
Nat	État naturel
O	Comme reçu
P	Décapé à l'acide
P_w	Décapé et lavé
Pl	Tôle
Pr	Pressé
Q	Trempé
Q_b	Trempé dans l'eau bouillante
Q_h	Trempé dans l'eau chaude
Q_i	Trempé dans saumure glacée
Q_{la}	Trempé dans l'air liquide
Q_o	Trempé dans l'huile
Q_w	Trempé dans l'eau
Q_{Pb}	Trempé dans un bain de plomb
Q_{salt}	Trempé dans un bain de sel
Q_2	Double trempe
R	Laminé
R_c	Laminé, froid
R_d	Laminé, dur
R_h	Laminé, chaud
R_s	Laminé, mou
S	Bien recuit
S_h	Bien recuit dans un bain chaud
Str	Frappé (dans matrice à monnaies)
Sv	Comme utilisé
Sw	Étampé
Tp	Revenu
Tp_o	Revenu à l'huile
Tp_2	Revenu deux fois
Trt	Traité thermiquement
U	Raffiné
V	Vieilli
W	Chauffé à
W_{gf}	Chauffé dans un four à gaz
W_s	Chauffé lentement
W_2	Rechauffé
$Wt°/x$	Chauffé à t°C et maintenu à cette température pendant x minutes
$Wt°/x$h	Chauffé à t°C et maintenu à cette température pendant x heures
W	Chaleur rouge blanc
Wk	Travaillé
Wk_c	Travaillé, froid
Wk_d	Travaillé, dur
Wk_h	Travaillé, chaud
Wk_s	Travaillé, mou
Y	Chaleur rouge jaune

Gr	Geschliffen
Gr_w	Nass geschliffen
H	Gehärtet
H_a	Luftgehärtet
H_o	Ölgehärtet
$H_{1/2}$	Halb gehärtet
H_{wk}	Kalt gehärtet
Hm	Gehämmert
J	Geprüft (bei t°C) oder (gleich)
J_a	Geprüft in Luft
J_{CO_2}	Geprüft in CO_2
J_{H_2}	Geprüft in H_2
J_{la}	Geprüft in flüssiger Luft
J_{N_2}	Geprüft in N_2
K	Gekohlt
M	Geändert
Ml	Geschmolzen
Ml_2	Umgeschmolzen
Ml_v	In Luftleere geschmolzen
N	Normalisiert
N_a	In Luft normalisiert
N_v	In Luftleere normalisiert
Nat	Natürlicher Zustand
O	Wie erhalten
P	Abgebeizt
P_w	Dito und gewaschen
Pl	Blech
Pr	Gepresst
Q	Abgeschreckt
Q_b	Dito in kochendem Wasser
Q_h	Dito in heissem Wasser
Q_i	Abgelöscht in Eislake
Q_{la}	Dito in flüssiger Luft
Q_o	Dito in Öl
Q_w	Dito in Wasser
Q_{Pb}	Dito im Bleibad
Q_{salt}	Dito im Salzbad
Q_2	Zweimal abgeschreckt
R	Gewalzt
R_c	Kalt gewalzt
R_d	Hart gewalzt
R_h	Heiss gewalzt
R_s	Weich gewalzt
S	Geweicht
S_h	Geweicht in heissem Bad
Str	Ins Münzgesenk geschlagen
Sv	Wie zum Gebrauch
Sw	Im Gesenk nachgeschmiedet
Tp	Angelassen
Tp_o	In Öl angelassen
Tp_2	Nochmals angelassen
Trt	Wärmebehandelt
U	Raffiniert
V	Gealtert
W	Erhitzt auf
W_{gf}	Im Gasofen erhitzt
W_s	Langsam erhitzt
W_2	Wiederholt erhitzt
$Wt°/x$	Erhitzt auf t° u. x Min. lang
$Wt°/xh$	Erhitzt auf t° u. x Std. lang
W	Weissglut
Wk	Bearbeitet (geschmiedet)
Wk_c	Kalt geschmiedet
Wk_d	Hart geschmiedet
Wk_h	Heiss geschmiedet
Wk_s	Weich geschmiedet

$H_{1/2}$	Semiduro
H_{wk}	Incrudito
Hm	Lavorato al maglio
J	Provato (a t°C) oppure (immediatemente)
J_a	Provato in aria
J_{CO_2}	Provato in CO_2
J_{H_2}	Provato in H_2
J_{la}	Provato in aria liquida
J_{N_2}	Provato in N_2
K	Carburazzato
M	Modificato
Ml	Fuso
Ml_2	Rifuso
Ml_v	Fuso nel vuoto
N	Normalizzato
N_a	Normalizzato all'aria
N_v	Normalizzato nel vuoto
Nat	Stato naturale
O	Nelle condizioni in cui è stato ricevuto
P	Pulito con acido
P_w	Pulito e lavato
Pl	Lamiera
Pr	Pressato
Q	Temprato in un liquido
Q_b	Temprato in acqua bollente
Q_h	Temprato in acqua calda
Q_i	Temprato in acqua salata ghiacciata
Q_{la}	Temprato in aria liquida
Q_o	Temprato in olio
Q_w	Temprato in acqua
Q_{Pb}	Temprato in bagno di piombo
Q_{salt}	Temprato in bagno di sali
Q_2	Doppia tempra
R	Laminato
R_c	Laminato a freddo
R_d	Laminato duro
R_h	Laminato a caldo
R_s	Laminato dolce
S	Ricotto a fondo
S_h	Ricotto a fondo in bagno caldo
Str	Stampato con pressa a coniare
Sv	Come per servizio
Sw	Forgiato su stampo
Tp	Rinvenuto
Tp_o	Rinvenuto in olio
Tp_2	Rinvenuto due volte
Trt	Trattato termicamente
U	Affinato
V	Invecchiato
W	Riscaldato a
W_{gf}	Riscaldato in un forno a gas
W_s	Riscaldato lentemente
W_2	Riscaldato due volte
$Wt°/x$	Riscaldato a t°C e mantenuto a questa temperatura per x minuti
$Wt°/xh$	Riscaldato a t°C e mantenuto a questa temperatura per x ore
W	Temperatura del bianco
Wk	Lavorato (grezzo)
Wk_c	Lavorato a freddo
Wk_d	Lavorato duro
Wk_h	Lavorato a caldo
Wk_s	Lavorato dolce
Y	Temperatura del color giallo

⊤ Tangential
↗ Radial

In the case of single crystals, the following are used:

Crys. ‖ Parallel to crystal axis
Crys. ⊥ Perpendicular to crystal axis

ABBREVIATIONS AND SYMBOLS DENOTING VARIABLES DEFINING A SYSTEM AND THEIR UNITS

a	Area of cross section
CS	Compressive stress
Ga	Gage
l	Length (gage length in case of tensile specimens)
l_0	Original length
Δl	Increment of length
p	Pressure
P	Load
SWG	Steel wire gage
Tr.	Trace (in analysis)
V	Volume
ΔV	Increment of volume
V_0	Original volume
d	Diameter
Δd	Increment of diameter
d_0	Original diameter

MEANINGS OF SYMBOLS DENOTING PROPERTIES

NOTE: Some of these properties are defined on p. viii, and the definitions are here referred to by number as Def. 1, Def. 2, etc.

A, B, C, D, etc.	Thermal coefficients of volume expansion; *v.* vol. I, p. 36.
a^2	Capillary constant; *v.* vol. I, p. 35
A_{c_1}, A_{c_2}, A_{c_3}, A_{r_1}, A_{r_2}, A_{r_3}	Critical temperatures or ranges of steels
BHN	Brinell hardness number (Def. 12)
BMR	Bending modulus of rupture, kg/mm² (Def. 5)
$C_{t_1}^{t_2}$	Mean specific heat between t_1° and t_2°C, joule/g
d_4^{20}	Specific gravity at 20° referred to water at 4°
DL_C	Deformation limit in compression, kg/mm²
E	Young's modulus, kg/mm² (Def. 10)
El	Elongation, % (Def. 7), gage lengths indicated by subscripts as follows: a = 2 in., b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in., l = 66.67 × (cross section area)$^{1/2}$, s = 4 × (cross section area)$^{1/2}$
EL	Elastic limit in tension, kg/mm² (Def. 2)
EL_C	Elastic limit in compression, kg/mm² (Def. 2)
EL_S	Elastic limit in shear (or torsion), kg/mm² (Def. 2)
EP	Extrusion pressure, kg/mm²
FL_0	Endurance limit to fatigue, kg/mm² (Def. 17*b*)
F. P.	Freezing point, °C
G	Modulus of elasticity in shear, kg/mm² (Def. 11)
IHN	Impact hardness number
IS	Impact strength, kg-m, machines and specimen type indicated by subscripts as follows: u = Izod, B. E. S. A. Std. specimen; v = Charpy, 45°V notch; w = Charpy, keyhole notch; x = Charpy, Mesnager notch; y = Fremont Square notch; z = U. S. N. Bureau of Aeronautics specimen (Def. 16)
IS'	Impact strength, kg-m/cm², on cross section at notch
K	Bulk modulus of elasticity, kg/mm²

En plus des signes ci-dessus, les signes suivants sont utilisés pour indiquer la position de l'éprouvette dans le lingot original, dans la gueuse, dans la barre laminée ou la tôle:

‖ Longitudinal ⊤ Tangentiel
⊥ Transversal ↗ Radial

Dans le cas des cristaux isolés, les signes suivants sont utilisés:

Crys. ‖ Parallèle à l'axe du cristal
Crys. ⊥ Perpendiculaire à l'axe du cristal

ABRÉVIATIONS ET SYMBOLES INDIQUANT LES VARIABLES DÉFINISSANT UN SYSTÈME ET LEURS UNITÉS

a	Surface de la section transversale	p	Pression
		P	Charge
CS	Effort de compression	SWG	Jauge en fil d'acier
Ga	Jauge	Tr.	Traces (en analyse)
l	Longueur (longueur entre repères dans le cas d'éprouvettes de traction)	V	Volume
		ΔV	Accroissement de volume
		V_0	Volume initial
		d	Diamètre
l_0	Longueur initiale	Δd	Accroissement du diamètre
Δl	Accroissement de longueur	d_0	Diamètre initial

SIGNIFICATION DES SYMBOLES INDIQUANT LES PROPRIÉTÉS

NOTE: Quelques-unes de ces propriétés sont définies à page viii et les définitions sont référées ici par un nombre comme suit: Def. 1, Def. 2, etc.

A, B, C, D, etc.	Coéfficients thermiques de dilatation cubique; *v.* vol. I, p. 36
a^2	Constante capillaire; *v.* vol. I, p. 35
A_{c_1}, A_{c_2}, A_{c_3}, A_{r_1}, A_{r_2}, A_{r_3}	Températures ou intervalles critiques des aciers
BHN	Nombre de dureté Brinell (Def. 12)
BMR	Module de rupture à la flexion, kg/mm² (Def. 5)
$C_{t_1}^{t_2}$	Chaleur spécifique moyenne entre t_1° et t_2° C, joules/g
d_4^{20}	Densité à 20° par rapport à l'eau à 4°
DL_C	Limite de déformation à la compression, kg/mm²
E	Module de Young, kg/mm² (Def. 10)
El	Allongement en pourcent (Def. 7), longueur entre repères indiquée par indices comme suit: a = 2 in.; b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in., l = 66,67 × (section transversale)$^{1/2}$, s = 4 × (section transversale)$^{1/2}$
EL	Limite élastique à la traction, kg/mm² (Def. 2)
El_C	Limite élastique à la compression, kg/mm² (Def. 2)
EL_S	Limite élastique au cisaillement (ou torsion), kg/mm² (Def. 2)
EP	Pression de matrice, kg/mm²
FL_0	Limite d'endurance à la fatigue, kg/mm² (Def. 17*b*)
F. P.	Point de congélation, °C
G	Module d'élasticité de glissement, kg/mm² (Def. 11)
IHN	Nombre de dureté au choc
IS	Résistance au choc, kg-m. Machines et éprouvettes types indiquées par des indices comme suit: u = Izod, B. E. S. A. Std. éprouvette type; v = Charpy, entaille en V 45°; w = Charpy, entaille en trou de clé; x = Charpy, entaille Mesnager; y = entaille carrée, Fremont; z = éprouvette type du U. S. N. Bureau

Y Gelbhitze

In dem Vorangegangenen werden nach die folgenden Zeichen hinzugefügt, welche die Stellung des Originalblockes, des gegossenen oder gewalzten Stückes, oder der Platte, angegeben:

|| Längs
⊥ Quer
⊤ Tangential
↗ Radial

Bei Einkristallen bedeuten die Zeichen:

Crys. || Gleichgerichtet zur Kristallachse
Crys. ⊥ Senrecht zur Kristallachse

ABKÜRZUNGEN UND ZEICHEN DER SYSTEMVARIABLEN UND DEREN EINHEITEN

a	Querschnitt (fläche)
CS	(Druck-) (Press-) spannung
Ga	Lehre
l	Messlänge im Falle der Zerreissproben
l_0	Ursprüngliche Länge
Δl	Zunahme der Länge
p	Druck
P	Belastung
SWG	Stahldrahtlehre
Tr.	Spuren (in Analyse)
V	Volumen
ΔV	Volumzunahme
V_0	Ausgangs- oder Ursprungsvolumen
d	Durchmesser
Δd	Zunahme des Durchmessers
d_0	Ursprünglicher Durchmesser

ZEICHEN FÜR EIGENSCHAFTEN

Bemerkung: Einige dieser Eigenschaften sind definiert p. viii. Sie sind unten noch durch die Bemerkung Def. 1, Def. 2, u.s.w. näher angegeben.

A, B, C, D, etc.	Koeff, der Wärmeausdehnung des Volumens; *siehe* vol. I, p. 36
a^2	Kapillaritätskonstante; *siehe* vol. I, p. 35
A_{c_1}, A_{c_2}, A_{c_3} / A_{r_1}, A_{r_2}, A_{r_3}	Kritische Temperaturen oder Umwandlungspunkte der Stähle
BHN	Brinellhärte (Kugeldruckhärte) (Def. 12)
BMR	Biegefestigkeit, kg/mm² (Def. 5)
$C_{t_1}^{t_2}$	Mittlere spez. Wärme zwischen t_1° und t_2°C, Joule/g
d_4^{20}	Spezifisches Gewicht
DL_C	Elastizitätsgrenze beim Druckversuch, kg/mm²
E	Young'scher Modul, kg/mm² (Def. 10)
El	Bruchdehnung in Prozenten der Messlänge (Def. 7), Lehren sind durch Indices angegeben und zwar: a = 2 in., b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in. l = 66,67 × Querschnitt$^{1/2}$, s = 4 × Querschnitt$^{1/2}$
EL	Elastizitätsgrenze beim Zugversuch, kg/mm² (Def. 2)
EL_C	Dito beim Druckversuch, kg/mm² (Def. 2)
EL_S	Schubelastizitätsgrenze (oder Drehung), kg/mm² (Def. 2)
EP	Ausstossdruck, kg/mm²
FL_0	Dauerbruchgrenze, kg/mm², (Def. 17*b*)
F. P.	Erstarrungspunkt, °C
G	Elastizitätsmodul für Scherbeanspruchung, kg/mm² (Def. 11)
IHN	Schlaghärte
IS	Schlagfestigkeit, kg-m. Maschinen und Materialprobe sind durch Indices angegeben, und zwar: u = Izod, B. E. S. A. Std. Probeform; v =

Oltre a queste indicazioni sono pure adoperati i segni seguenti a indicare la posizione dei provini nel lingotto nel getto o nella barra o lamiera originarii:

|| Longitudinale
⊥ Trasversale
⊤ Tangenziale
↗ Radiale

Nel caso dei singoli cristalli si usano i seguenti:

Crys. || Parallelo all'asse del cristallo
Crys. ⊥ Perpendicolare all'asse del cristallo

ABBREVIAZIONI E SIMBOLI INDICANTI VARIABILI CHE DEFINISCONO UN SISTEMA E LORO UNITÀ

a	Area della sezione trasversale	P	Carico
CS	Sforzo di compressione	SWG	Calibro per fili
Ga	Calibro	Tr.	Traccia (in analisi)
l	Lunghezza (calibro di lunghezza nel caso di provini di trazione)	V	Volume
		ΔV	Aumento di volume
		V_0	Volume originale
		d	Diametro
l_0	Lunghezza originaria	Δd	Aumento di diametro
Δl	Aumento di lunghezza	d_0	Diametro originario
p	Pressione		

SIGNIFICATO DI SIMBOLI INDICANTI PROPRIETÀ

Nota: Alcune di queste proprietà sono definite nella p. viii, e alle definizioni è qui fatto riferimento con numeri: Def. 1, Def. 2, ecc.

A, B, C, D, ecc.	Coefficiente di temperatura della dilatazione cubica; *v.*, vol. I, p. 36
a^2	Costante di capillarità; *v.* vol. I, p. 35
A_{c_1}, A_{c_2}, A_{c_3} / A_{r_1}, A_{r_2}, A_{r_3}	Temperature critiche o intervalli critici degli acciai
BHN	Numero di durezza Brinell (Def. 12)
BMR	Modulo di rottura alla flessione, kg/mm² (Def. 5)
$C_{t_1}^{t_2}$	Calore specifico medio tra t_1°, e t_2° C, joule/g
d_4^{20}	Peso specifico a 20° riferito all'acqua a 4°
DL_C	Limite di snervamento alla compressione, kg/mm²
E	Modulo di Young, kg/mm² (Def. 10)
El	Allungamento percentuale (Def. 7), i calibri sono indicati a mezzo di indici scritti di sotto a questo modo: a = 2 in., b = 3 in., c = 4 in., d = 100 mm, f = 180 mm, g = 200 mm, k = 20 in., l = 66,67 × (l'area della sezione trasversale)$^{1/2}$, = 4 × (l'area della sezione trasversale)$^{1/2}$
EL	Limite elastico alla trazione, kg/mm² (Def. 2)
EL_C	Limite elastico alla compressione, kg/mm² (Def. 2)
EL_S	Limite elastico al taglio (o torsione), kg/mm² (Def. 2)
EP	Pressione di matrice, kg/mm²
FL_0	Limite di durata alla fatica, kg/mm² (Def. 17*b*)
F. P.	Punto di congelamento, °C
G	Modulo di elasticità al taglio, kg/mm² (Def. 11)
IHN	Numero di durezza di resistenza all' urto
IS	Resistenza all' urto, kg-m. Macchina e tipo del provino sono indicati con indici scritti di sotto nella maniera che segue: u = Izod, provino B. E. S. A. Std.; v = Charpy, con intaglio V a 45°; w = Charpy, con intaglio buco della serratura; x = Charpy, con intaglio Mesnager; y = intaglio quadrato di Fremont; z = provino dello U. S. N. Bureau of Aeronautics (Def. 16)
IS'	Resistenza all' urto, kg/cm², sulla sezione utile

$k_{t_1}^{t_2}$	Mean thermal conductivity between t_1° and t_2°C, joules cm^{-2} sec^{-1} (°C, cm^{-1})
L_F	Latent heat of fusion, kilojoule/g-atom
L_V	Latent heat of vaporization, kilojoule/g-atom
l_V	Latent heat of vaporization, kilojoule/g
L_T	Latent heat of transformation, kilojoule/g-atom
LCH	Ludwik cone hardness
M	Molecular weight
M. P.	Melting point, °C
MS	Mean stress
MSH	Martens scratch hardness
No. B	Number of bends to fracture (Def. 15)
PL	Proportional limit in tension, kg/mm^2 (Def. 1)
PL_C	Proportional limit in compression, kg/mm^2 (Def. 1)
PL_S	Proportional limit in shear (or torsion), kg/mm^2 (Def. 1)
PS	Proof stress, kg/mm^2
R	Endurance range, kg/mm^2 (Def. 17*e*)
RA	Reduction in area, % (Def. 8)
RHN	Rockwell hardness number
ScH	Scleroscope hardness (Def. 13)
Shr.	Mold shrinkage, %
TMR	Torsional modulus of rupture, kg/mm^2 (Def. 6)
TSH	Turner scratch hardness
Tw	Twist in torsion test, °/cm, unless total twist is given
UBM	Ultimate bending moment
UCS	Ultimate compressive strength, kg/mm^2 (Def. 4)
USS	Ultimate shearing strength (measured directly), kg/mm^2 (Def. 4)
USS_C	Ultimate shearing strength, (computed from torsion test), kg/mm^2 (Def. 6, second equation)
UTS	Ultimate tensile strength, kg/mm^2 (Def. 4)
UWB	Ultimate work of bending, kg-m
v	Specific volume, g^{-1}
V. P.	Vapor pressure
YP	Yield point in tension, kg/mm^2 (Def. 3)
YP_C	Yield point in compression, kg/mm^2 (Def. 3)
YP_S	Yield point in shear (or torsion), kg/mm^2 (Def. 3)
$\alpha, \beta, \gamma, \delta$, etc.	Thermal coefficients of linear expansion; *v.* p. 459
γ	Surface tension; *v.* vol. I, p. 42.
ϵ	Per cent compression (under stated load)
η	Tangential or fluid coefficient of viscosity; *v.* vol. I, p. 42
ξ	Normal coefficient of viscosity
λ	Poisson's ratio (Def. 9)
ψ_p	$\frac{1}{\chi}\left(\frac{d\chi}{dp}\right)_t$ (Temperature constant)
ψ_t	$\frac{1}{\chi}\left(\frac{d\chi}{dt}\right)_p$ (Pressure constant)
χ	Compressibility (atmospheres)$^{-1}$

of Aeronautics (Def. 16)

IS'	Résistance au choc, kg-m/cm^2 sur la section à l'entaille
K	Module d'élasticité apparent, kg/mm^2
$k_{t_1}^{t_2}$	Conductibilité thermique moyenne entre t_1° et t_2° C, joules cm^{-2} sec^{-1} (°C, cm^{-1})
L_F	Chaleur latente de fusion, kilojoules/g-atome
L_V	Chaleur latente de vaporisation, kilojoules/g-atome
l_V	Chaleur latente de vaporisation, kilojoules/g
L_T	Chaleur latente de transformation, kilojoules/g-atome
LCH	Dureté Ludwik cone
M	Poids moléculaire
M. P.	Point de fusion, °C
MS	Effort moyen
MSH	Dureté Martens rayure
No. B	Nombre de pliages jusqu'à rupture (Def. 15)
PL	Limite de proportionnalité à la traction, kg/mm^2 (Def. 1)
PL_C	Limite de proportionnalité à la compression, kg/mm^2 (Def. 1)
PL_S	Limite de proportionnalité au cisaillement (ou torsion), kg/mm^2 (Def. 1)
PS	Effort d'épreuve, kg/mm^2
R	Amplitude d'endurance, kg/mm^2 (Def. 17*e*)
RA	Striction, % (Def. 8)
RHN	Nombre de dureté Rockwell
ScH	Dureté au scléroscope (Def. 13)
Shr.	Retrait au moulage, %
TMR	Module de torsion à la rupture, kg/mm^2 (Def. 6)
TSH	Dureté Turner à la rayure
Tw	Torsion dans l'essai de torsion °/cm, à moins que la torsion totale ne soit donnée
UBM	Moment de flexion ultime
UCS	Résistance à la compression, kg/mm^2 (Def. 4)
USS	Résistance au cisaillement (mesurée directement), kg/mm^2 (Def. 4)
USS_C	Résistance au cisaillement (déduite de l'essai de torsion), kg/mm^2 (Def. 6, deuxième équation)
UTS	Résistance à la traction, kg/mm^2 (Def. 4)
UWB	Travail ultime de flexion, kg-m
v	Volume spécifique, g^{-1}
V. P.	Pression de vapeur
YP	Limite d'étirage ou d'écoulement à la traction, kg/mm^2 (Def. 3)
YP_C	Limite d'étirage à la compression, kg/mm^2 (Def. 3)
YP_S	Limite de cisaillement (ou de torsion), kg/mm^2 (Def. 3)
$\alpha, \beta, \gamma, \delta$, etc.	Coéfficients thermiques de dilatation linéaire; *v.* p. 459
γ	Tension de surface; *v.* vol. I, p. 42
ϵ	Pourcent de compression (sous une charge donnée)
η	Coéfficient de viscosité, tangentiel ou fluide; *v.* vol. I, p. 42
ξ	Coéfficient de viscosité normal
λ	Coéfficient de Poisson (Def. 9)
ψ_p	$\frac{1}{\chi}\left(\frac{d\chi}{dp}\right)_t$ (Température constante)
ψ_t	$\frac{1}{\chi}\left(\frac{d\chi}{dt}\right)_p$ (Pression constante)
χ	Compressibilité (atmosphères)$^{-1}$

Charpy, V-Kerbe, 45°; w = Charpy, Schlüssloch-Rille; x = Charpy, Mesnager-Rille; y = Fremont-Rille mit quadratischen Querschnitt; z = Probeform des U. S. N. Bureau of Aeronautics (Def. 16)

IS'	Schlagfestigkeit, kg-m/cm²
K	Durchschnittlicher Elastizitätsmodul, kg/mm²
$k_{t_1}^{t_2}$	Mittlere Wärmeleitfähigkeit zwischen t_1° und t_2° C, Joule cm⁻² sec⁻¹ (°C, cm⁻¹)
L_F	Schmelzwärme, Kilojoule/g-atom.
L_V	Verdampfungswärme, Kilojoule/g-atom.
l_V	Verdampfungswärme, Kilojoule/g
L_T	Umwandlungswärme, Kilojoule/g-atom.
LCH	Kegelhärte nach Ludwik
M	Molekulargewicht
M. P.	Schmelzpunkt, °C
MS	Mittlerer Druck
MSH	Ritzhärte nach Martens
No. B	Zahl der Biegungen (Def. 15)
PL	Proportionalitätsgrenze beim Zugversuch, kg/mm² (Def. 1)
PL_C	Dito beim Druckversuch, kg/mm² (Def. 1)
PL_S	Dito beim Schubversuch (oder Drehung), kg/mm² (Def. 1)
PS	Prüfspannung, kg/mm²
R	Dauerbruchfestigkeit für bestimmte Spannungswechsel, kg/mm² (Def. 17*e*)
RA	Brucheinschnürung in % (Def. 8)
RHN	Rockwellhärtezahl
ScH	Skleroskophärte (Def. 13)
Shr.	Schwindung in %
TMR	Drehfestigkeit, kg/mm² (Def. 6)
TSH	Ritzhärte nach Turner
Tw	Verdrehung in °/cm beim Drehversuch
UBM	Biegungshöchstmoment
UCS	Druckfestigkeit, kg/mm² (Def. 4)
USS	Scherfestigkeit, kg/mm² (Def. 4)
USS_C	Dito durch Drehversuch bestimmt, kg/mm² (Def. 6, zweite Gleichung)
UTS	Zugfestigkeit, kg/mm² (Def. 4)
UWB	Grösstbiegearbeit, kg-m
v	Spez. Volumen, g⁻¹
V. P.	Dampfdruck
YP	Fliessgrenze, kg/mm² (Def. 3)
YP_C	Quetschgrenze, kg/mm² (Def. 3)
YP_S	Fliessgrenze beim Scher- (Dreh-) versuch, kg/mm² (Def. 3)
$\alpha, \beta, \gamma, \delta$, etc.	Linearer Wärmeausdehnungskoeffizient; *siehe*, p. 459
γ	Oberflächenspannung; *siehe* vol. I, p. 42
ϵ	Prozent Zusammenpressung unter statischer Belastung
η	Tangential- oder Viskositäts-Koeffizient; *siehe* vol. I, p. 42
ξ	Normaler Viskositätskoeffizient
λ	Verhältnis nach Poisson (Def. 9)
ψ_p	$\frac{1}{\chi}\left(\frac{d\chi}{dp}\right)_t$ (Temp. Konst.)
ψ_t	$\frac{1}{\chi}\left(\frac{d\chi}{dt}\right)_p$ (Druck Konst.)
χ	Kompressibilität (atmosph.)⁻¹

K	Modulo di elasticità alla compressione, kg/mm²
$k_{t_1}^{t_2}$	Conducibilità termica media tra t_1° e t_2°C, joule cm⁻² sec⁻¹ (°C, cm⁻¹)
L_F	Calore latente di fusione, kilojoule/g-atomo
L_V	Calore latente di evaporazione, kilojoule/g-atomo
l_V	Calore latente di evaporizione, kilojoule/g
L_T	Calore latente di trasformazione, kilojoule/g-atomo
LCH	Durezza al cono Ludwik
M	Peso molecolare
M. P.	Punto di fusione, °C
MS	Sforzo medio
MSH	Durezza alla scalfittura secondo Martens
No. B	Numero di piegature per arrivare a frattura (Def. 15)
PL	Limite di proporzionalità alla tensione, kg/mm² (Def. 1)
PL_C	Limite di proporzionalità alla compressione, kg/mm² (Def. 1)
PL_S	Limite di proporzionalità al taglio (o torsione), kg/mm² (Def. 1)
PS	Carico di prova, kg/mm²
R	Ampiezza di durata alla fatica, kg/mm² (Def. 17*e*)
RA	Riduzione di area percentuale (Def. 8)
RHN	Numeri di durezza Rockwell
ScH	Durezza scleroscopica (Def. 13)
Shr.	Ritiro percentuale nella forma
TMR	Modulo di rottura alla torsione, kg/mm² (Def. 6)
TSH	Durezza alla scalfittura secondo Turner
Tw	Angolo di torsione espresso in gradi per centimetro, a meno che non sia data la torsione totale
UBM	Carico di rottura alla flessione
UCS	Carico di rottura per compressione, kg/mm² (Def. 4)
USS	Carico di rottura per taglio (misura direttamente), kg/mm² (Def. 4)
USS_C	Carico di rottura per taglio (calcolato dal saggio di torsione), kg/mm² (Def. 6, equazione secondo)
UTS	Carico di rottura alla trazione, kg/mm² (Def. 4)
UWB	Lavoro di rottura per flessione, kg-m
v	Volume specifico, g⁻¹
V. P.	Tensione di vapore
YP	Limite di snervamento alla trazione, kg/mm² (Def. 3)
YP_S	Limite di snervamento alla compressione, kg/mm² (Def. 3)
YP_S	Limite di snervamento al taglio (o torsione), kg/mm² (Def. 3)
$\alpha, \beta, \gamma, \delta$, ecc.	Coefficienti di temperatura della dilatazione lineare; *v.* p. 459
γ	Tensione superficiale; *v.* vol. I, p. 42
ϵ	Compressione percentuale (sotto un carico statico)
η	Coefficiente tangenziale o fluido di viscosità; *v.* vol. I, p. 42
ξ	Coefficiente normale di viscosità
λ	Rapporto di Poisson (Def. 9)
ψ_p	$\frac{1}{\chi}\left(\frac{d\chi}{dp}\right)_t$ (Costante di temperatura)
ψ_t	$\frac{1}{\chi}\left(\frac{d\chi}{dt}\right)_p$ (Costante di pressione)
χ	Compressibilità (atmosfere)⁻¹

EQUILIBRIUM DIAGRAMS

CONTENTS

INTRODUCTION

The vapor phase is not considered, vapor pressure being very small with respect to atmospheric pressure with few exceptions, such as As.

The liquid phase is denoted by Liq., or if more than one liquid phase exists, by Liq. I, Liq. II, etc.

Crystal phases are designated as follows:

A metal or intermetallic compound by its chemical formula.

A solid solution of A in B by (A, B).

If A is a compound, this does not mean necessarily that molecules of A exist in solution; most X-rays data are to the contrary. Crystals of the composition A, however, do separate from the solid solution.

A solid solution of A and B in all proportions by [A, B].

A solid solution of A or B in the compound A_xB_y by (A_xB_y).

A series of different solid solutions by α, β, γ, δ, etc., their composition being stated if known.

A mixture of A and B by A + B.

A binary eutectic in a ternary system by e.

A ternary eutectic by E.

The eutectic temperature of binary alloys is indicated by a dot and dash line.

All temperatures are in °C, and unless otherwise indicated all compositions are in weight %.

ALUMINIUM ALLOYS

M. L. V. Gayler

INDEX OF SYSTEMS

* Two immiscible liquid phases.

LITERATURE

(For a key to the periodicals see end of volume)

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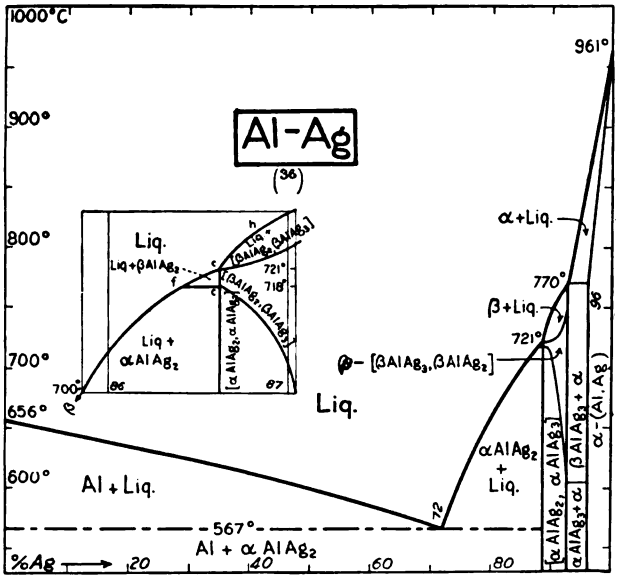
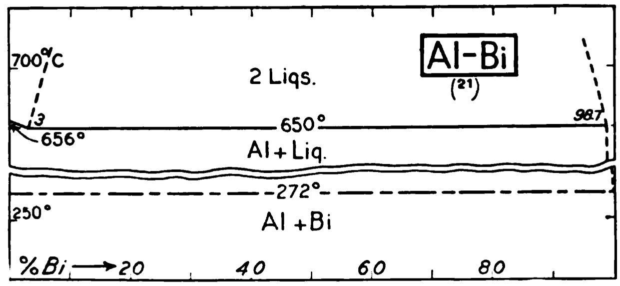
(10) Chouriguine, *74*, **9**: 874; 12. (11) Curry, *50*, **11**: 425; 07. (11.1) Dix and Richardson, *80*, Preprint 1534-E; 26. (12) Doerinckel, *93*, **48**: 185; 06. (13) Donski, *93*, **57**: 185; 08. (14) Edwards, *33*, **28**: 165; 23. (15) Eger, *95*, **4**: 29; 13. (15.1) Eger, *95*, **53**: 545; 23. (16) Erckelens, *187*, **20**: 206; 23. (17) Fraenkel, *93*, **58**: 154; 08. (18) Gayler, *47*, **28**: 213; 22. (19) Gayler, *47*, **29**: 507; 23.

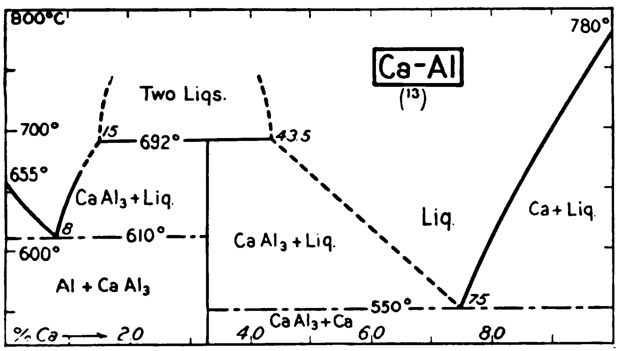
(20) Gayler, *47*, **30**: 139; 23. (21) Gwyer, *93*, **49**: 311; 06. (22) Gwyer, *93*, **57**: 113; 08. (23) Hanson and Gayler, *47*, **24**: 201; 20. (24) Hanson and Gayler, *47*, **26**: 321; 21. (25) Hanson and Gayler, *47*, **27**: 267; 22. (26) Haughton and Bingham, *5*, **99**: 47; 21. (27) Heycock and Neville, *62*, **194**: 201; 00. (28) Heycock and Neville, *62*, **214**: 267; 14. (29) Heycock and Neville, *5*, **90**: 560; 14.

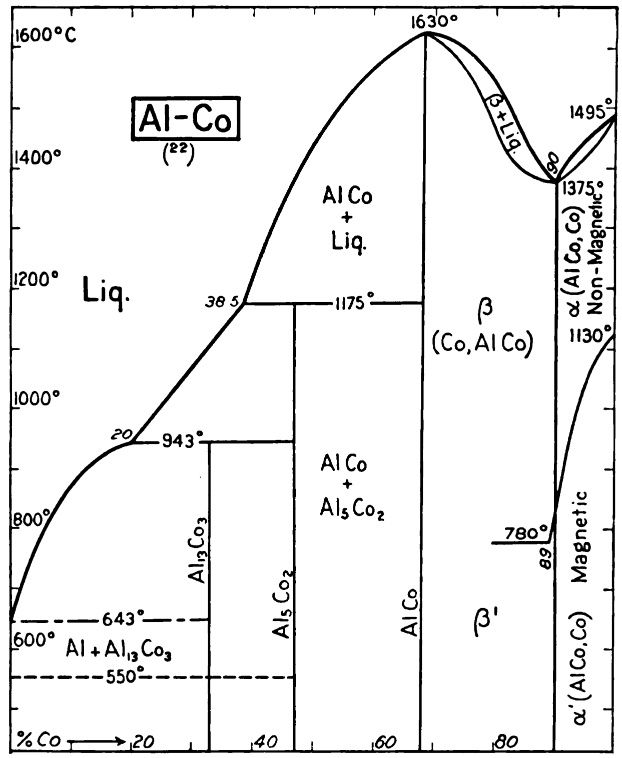
(30) Hindricks, *93*, **59**: 414; 08. (30.1) Honda and Ishigaki, *159*, **14**: 219; 25. (30.2) Isihara, *159*, **15**: 209; 26. (31) von Jares, *95*, **10**: 1; 19. (32) Kurnakov, Urasov and Grigorjev, *93*, **125**: 207; 22. (33) Losana and Carozzi, *36*, **53**: 546; 23. (34) Mathewson, *93*, **48**: 191; 06. (35) Oesterheld, *93*, **97**: 6; 16. (36) Petrenko, *93*, **46**: 49; 05. (37) Roberts, *4*, **105**: 1383; 14. (38) Rosenhain and Archbutt, *62*, **211 A**: 315; 11. (39) Rosenhain and Archbutt, *5*, **85**: 389; 11.

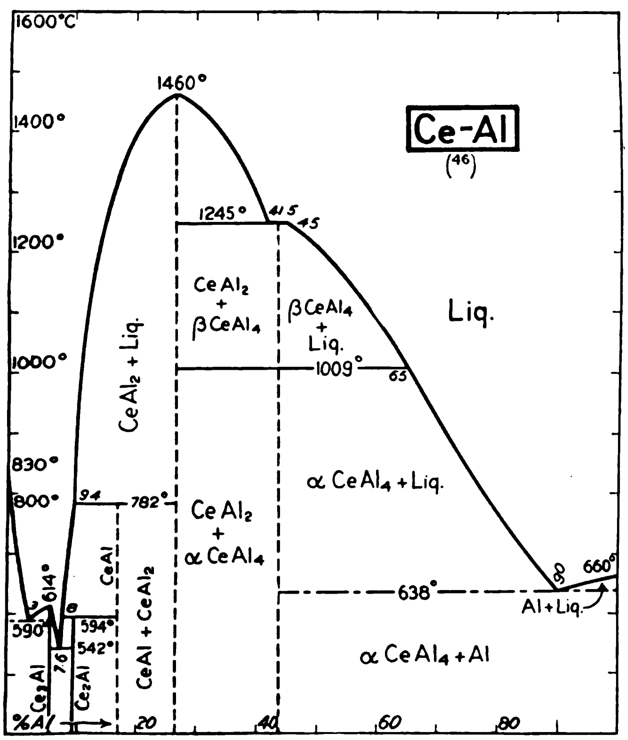
(40) Rosenhain, Archbutt and Hanson, *403*, **1921 II**: 699. (41) Rosenhain and Lantsberry, *403*, **1910 I**: 119. (42) Smith, *93*, **56**: 109; 07. (43) Smits and de Gruyter, Univ. of Amsterdam, *O*. (44) Stockdale, *47*, **28**: 273; 22. (45) Stockdale, *47*, **31**: 275; 24. (46) Vogel, *93*, **75**: 41; 12. (47) Vogel, *93*, **107**: 265; 19.

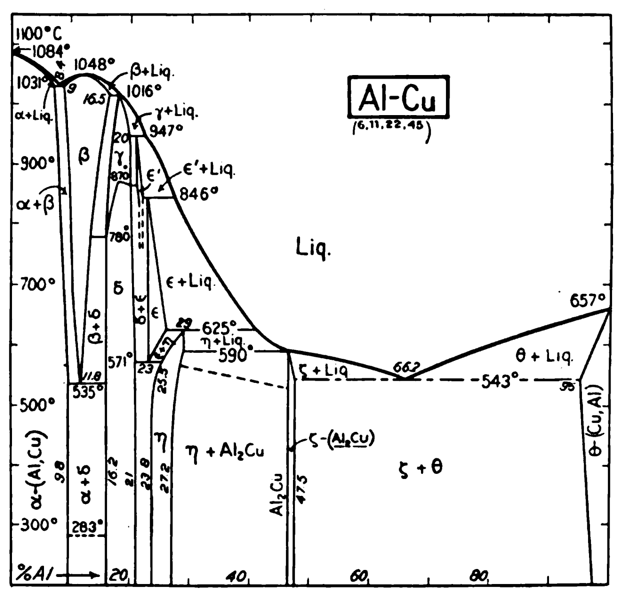

Al-Ag
(36)
1000°C
961°
900°
800°
700°
656°
600°
Liq.
Liq + βAlAg₂
Liq + αAlAg₂
721°
718°
700°
Liq.
α+Liq.
770°
β+Liq.
721°
β- [βAlAg₃, βAlAg₂]
αAlAg₂ + Liq.
Al + Liq.
567°
Al + α AlAg₂
72
96
%Ag → 20 40 60 80


Al-Bi
(21)
700°C
2 Liqs.
650°
656°
98.7
Al + Liq.
272°
250°
Al + Bi
%Bi → 20 40 60 80

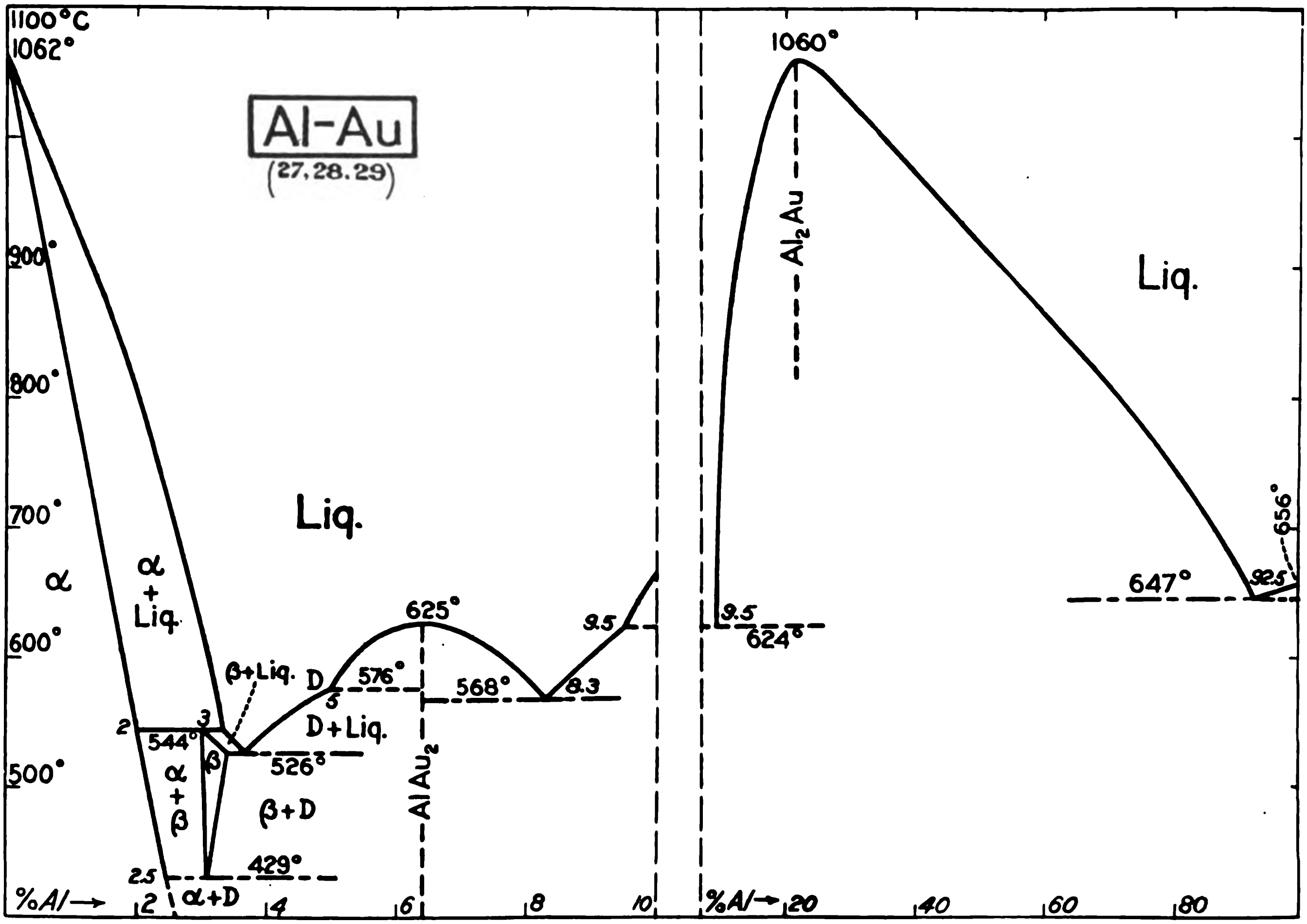

Ca-Al
(13)
800°C
780°
Two Liqs.
700°
15
692°
43.5
655°
CaAl₃ + Liq.
610°
600°
8
CaAl₃ + Liq.
Liq.
Ca + Liq.
Al + CaAl₃
550°
75
CaAl₃ + Ca
%Ca → 20 40 60 80


Al-Co
(22)
1630°
1600°C
1495°
β+Liq.
1400°
90
1375°
AlCo + Liq.
1200°
Liq.
38.5
1175°
β (Co, AlCo)
α (AlCo, Co) Non-Magnetic
1130°
1000°
20
943°
AlCo + Al₅Co₂
800°
780°
89
Magnetic
Al₁₃Co₃
Al₅Co₂
AlCo
β'
643°
600°
Al + Al₁₃Co₃
550°
α' (AlCo, Co)
%Co → 20 40 60 80

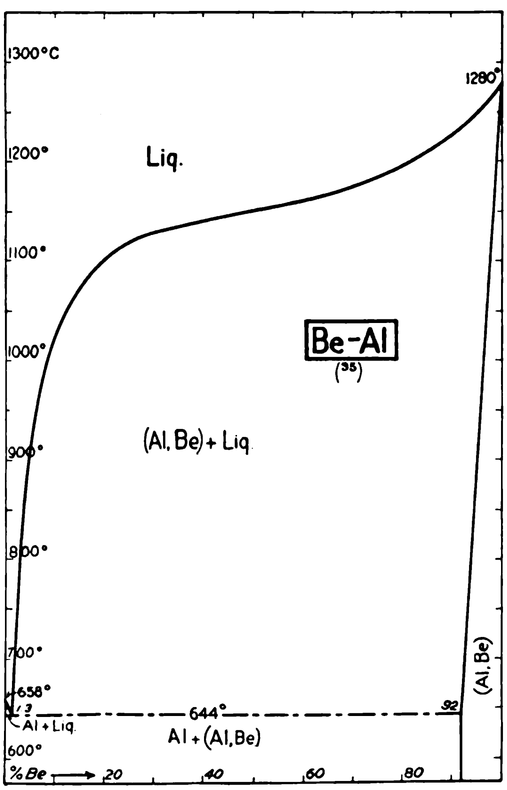

Ce-Al
(46)
1600°C
1460°
1400°
1245°
41.5
45
1200°
CeAl₂ + βCeAl₄
βCeAl₄ + Liq.
Liq.
1000°
CeAl₂ + Liq.
1009°
65
830°
800°
94
782°
CeAl₂ + α CeAl₄
α CeAl₄ + Liq.
614°
CeAl
638°
90
660°
590°
8
594°
542°
CeAl + CeAl₂
Al + Liq.
7.6
Ce₃Al
Ce₂Al
α CeAl₄ + Al
%Al → 20 40 60 80


Al-Cu
(6, 11, 22, 45)
1100°C
1084°
1048°
β+Liq.
1031°
1016°
α+Liq.
γ+Liq.
947°
900°
β
γ
ε'
ε'+Liq.
846°
α+β
780°
Liq.
700°
δ
ε+Liq.
657°
β+δ
δ+ε
ε
625°
η+Liq.
590°
571°
ζ+Liq.
662
θ + Liq.
543°
535°
500°
α-(Al,Cu)
α+δ
η
η + Al₂Cu
ζ-(Al₂Cu)
ζ + θ
θ-(Cu, Al)
Al₂Cu
300°
283°
%Al → 20 40 60 80

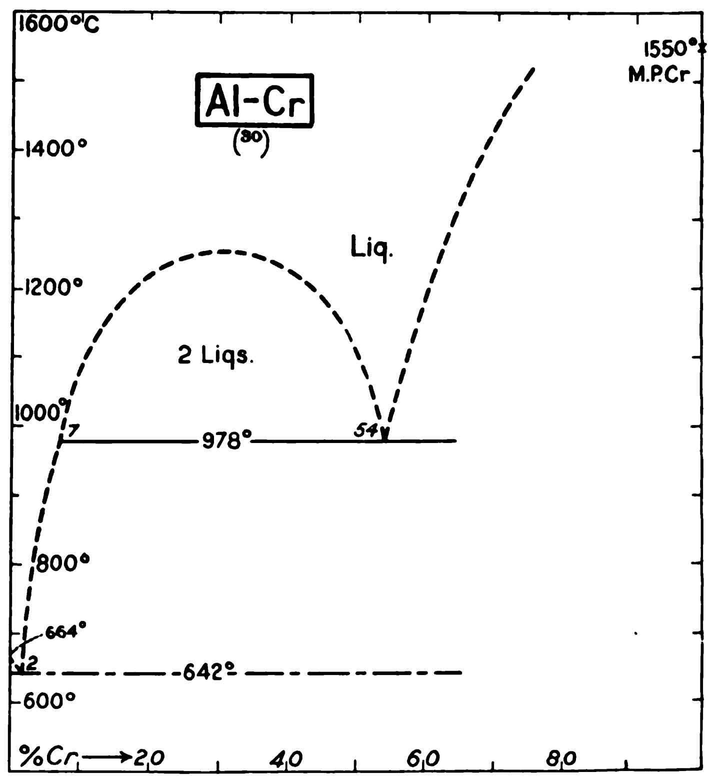
See p. 609



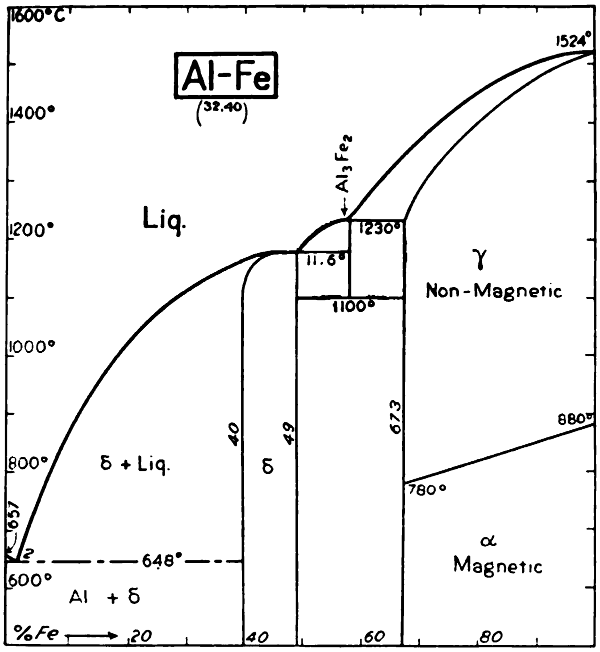
Al-Au
(27, 28, 29)
1100°C
1062°
900°
800°
700°
600°
500°
α
α + Liq.
Liq.
β+Liq.
D
576°
625°
568°
8.3
9.5
2
3
5
544°
526°
D + Liq.
α + β
β
β+D
AlAu2
429°
2.5
α+D
%Al→
2
4
6
8
10
1060°
Al2Au
Liq.
647°
92.5
656°
9.5
624°
%Al→
20
40
60
80

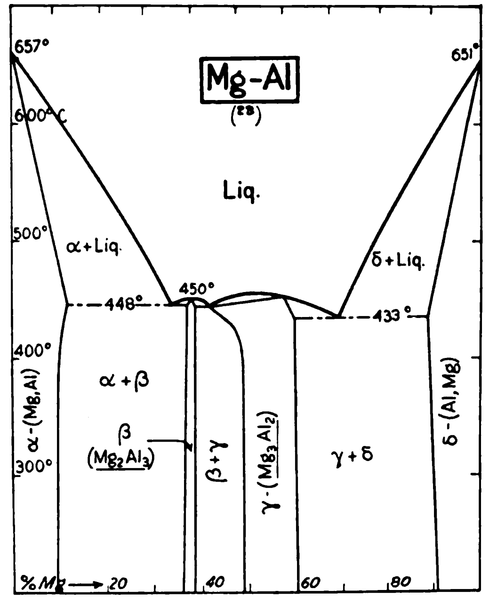


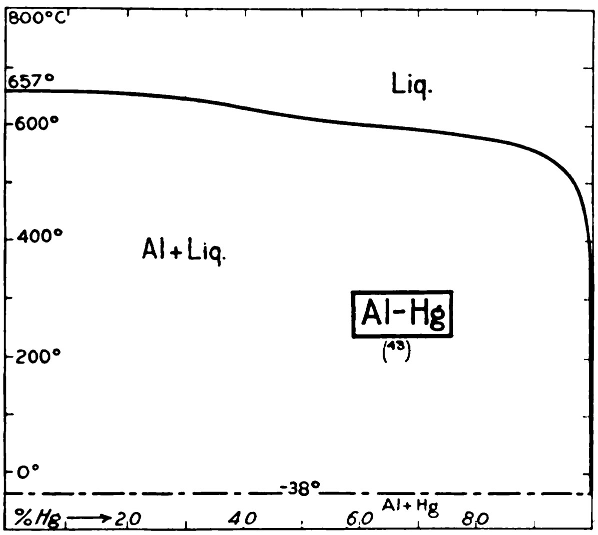
1300°C
1200°
1100°
1000°
900°
800°
700°
600°
1280°
Liq.
Be-Al
(35)
(Al, Be) + Liq.
658°
1.3
644°
92
Al + Liq.
Al + (Al, Be)
(Al, Be)
%Be
20
40
60
80

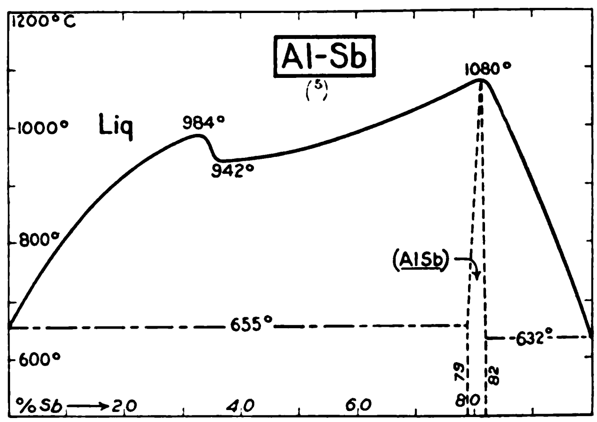


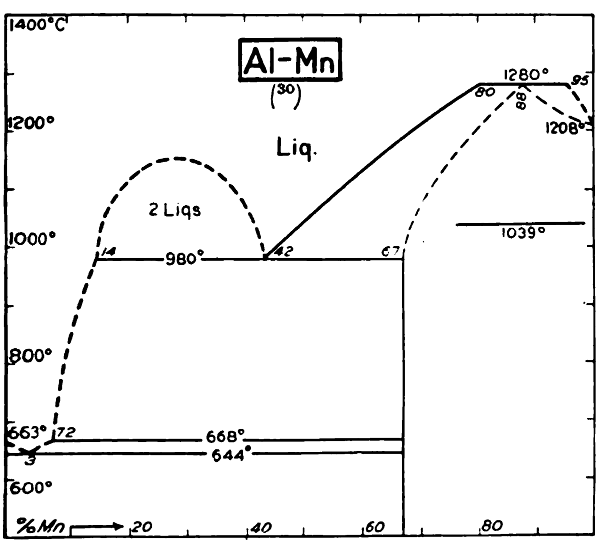
1600°C
1550°±
M.P.Cr.
Al-Cr
(30)
1400°
Liq.
1200°
2 Liqs.
1000°
7
978°
54
800°
664°
2
642°
600°
%Cr
20
40
60
80

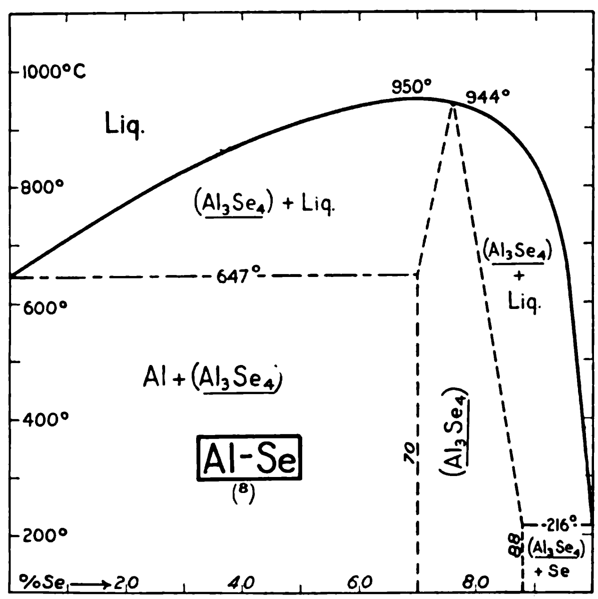

Al-Fe
(32.40)
1600°C
1400°
1200°
1000°
800°
600°
1524°
Liq.
Al₃Fe₂
1230°
11.6°
1100°
γ
Non-Magnetic
880°
780°
δ + Liq.
δ
40
49
673
657
2
648°
Al + δ
α
Magnetic
%Fe → 20
40
60
80

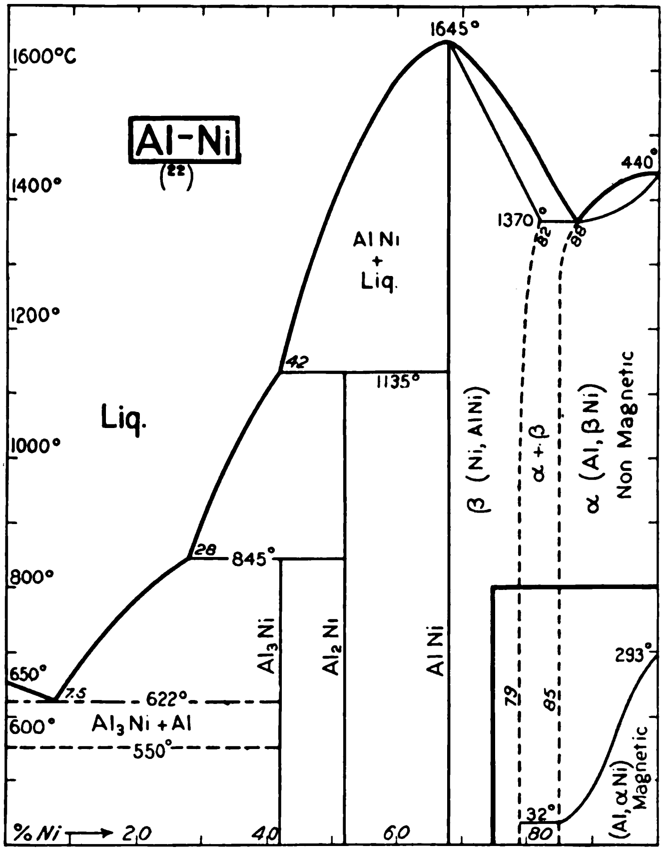

Mg-Al
(23)
657°
651°
600°C
500°
400°
300°
Liq.
α+Liq.
δ+Liq.
450°
448°
433°
α+β
β
(Mg₂Al₃)
β+γ
γ-(Mg₃Al₂)
γ+δ
α-(Mg,Al)
δ-(Al,Mg)
%Mg → 20
40
60
80

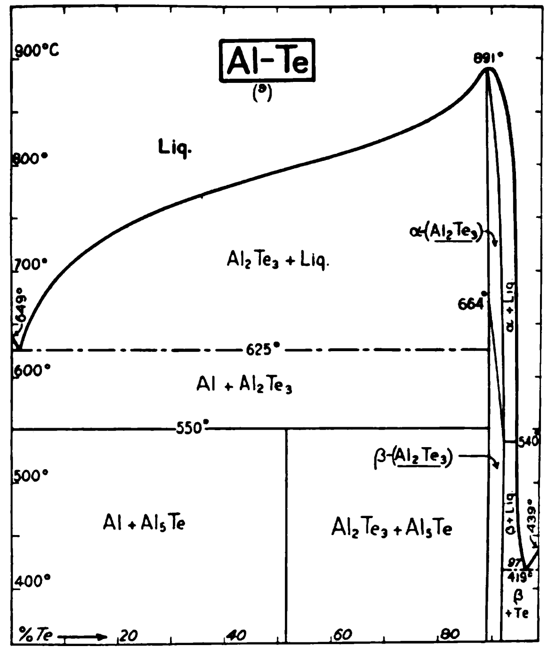

800°C
657°
600°
400°
200°
0°
Liq.
Al+Liq.
Al-Hg
(43)
-38°
Al+Hg
%Hg → 20
40
60
80

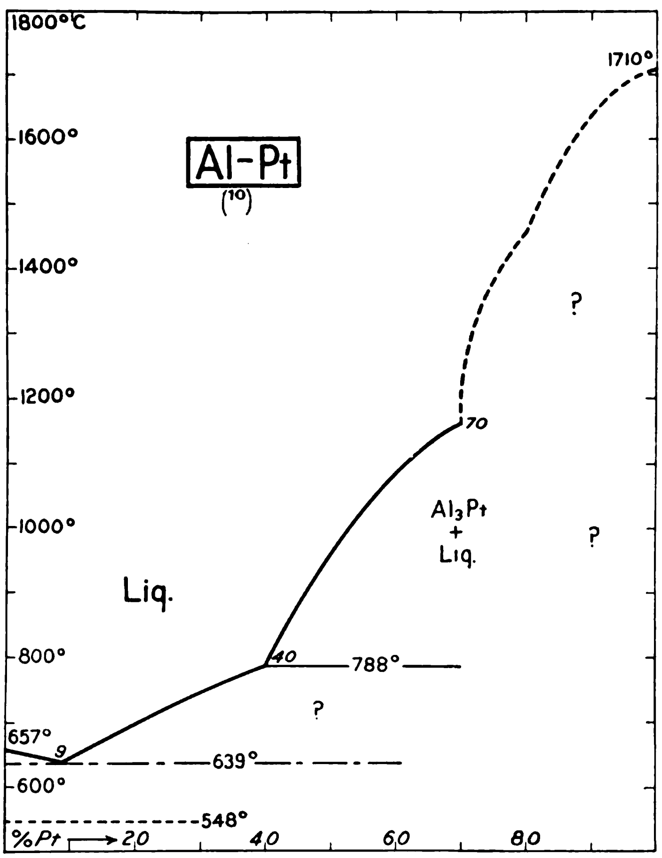

1200°C
Al-Sb
(5)
1080°
1000°
Liq
984°
942°
800°
(AlSb)
655°
632°
600°
79
82
81
%Sb → 20
40
60

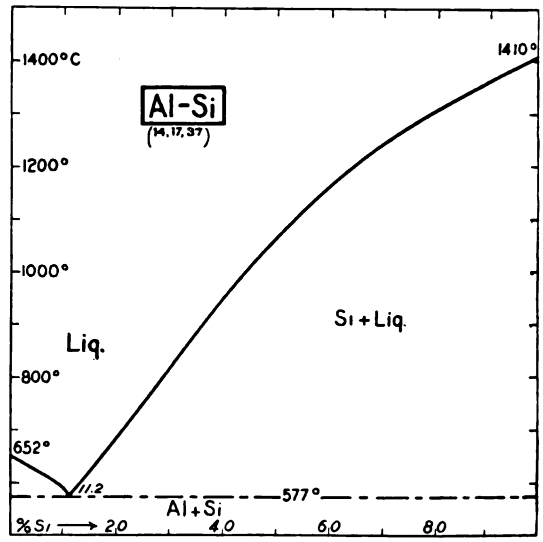

1400°C
Al-Mn
(30)
1200°
1000°
800°
600°
Liq.
2 Liqs
1280°
80
88
95
1208°
1039°
14
980°
42
67
663°
72
3
668°
644°
%Mn → 20
40
60
80

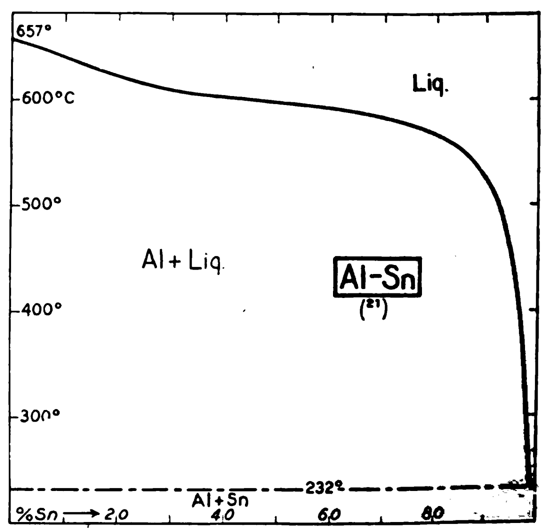

1000°C
950°
944°
Liq.
800°
(Al₃Se₄) + Liq.
(Al₃Se₄)
+
Liq.
647°
600°
Al + (Al₃Se₄)
400°
Al-Se
(8)
70
(Al₃Se₄)
88
-216°
(Al₃Se₄)
+ Se
200°
%Se → 20
40
60
80

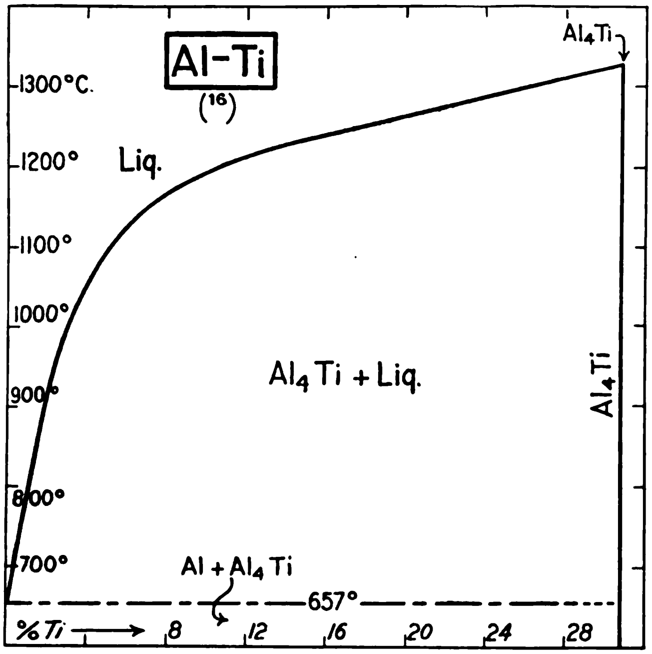

Al-Ni
(22)
1645°
1600°C
1400°
1200°
1000°
800°
650°
600°
440°
1370°
82
88
Al Ni
+
Liq.
42
1135°
Liq.
28
845°
7.5
622°
550°
Al3 Ni + Al
Al3 Ni
Al2 Ni
Al Ni
β (Ni, Al Ni)
α + β
α (Al, β Ni)
Non Magnetic
79
85
293°
32°
80
(Al, α Ni) Magnetic
% Ni → 20 40 60

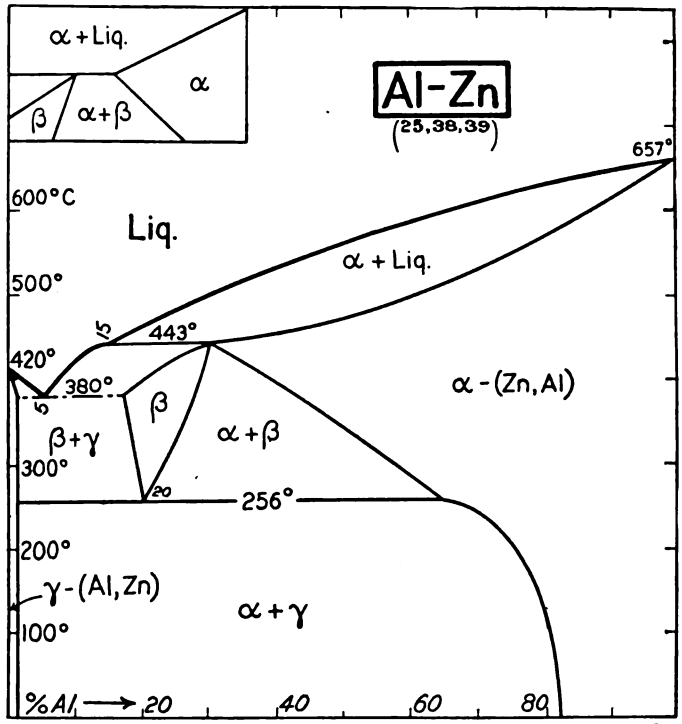

Al-Te
(9)
900°C
891°
800°
Liq.
700°
Al2 Te3 + Liq.
α-(Al2 Te3)
649°
664°
α + Liq
625°
600°
Al + Al2 Te3
550°
500°
540°
β-(Al2 Te3)
Al + Al5 Te
Al2 Te3 + Al5 Te
α + Liq
439°
400°
97
419°
β + Te
% Te → 20 40 60 80

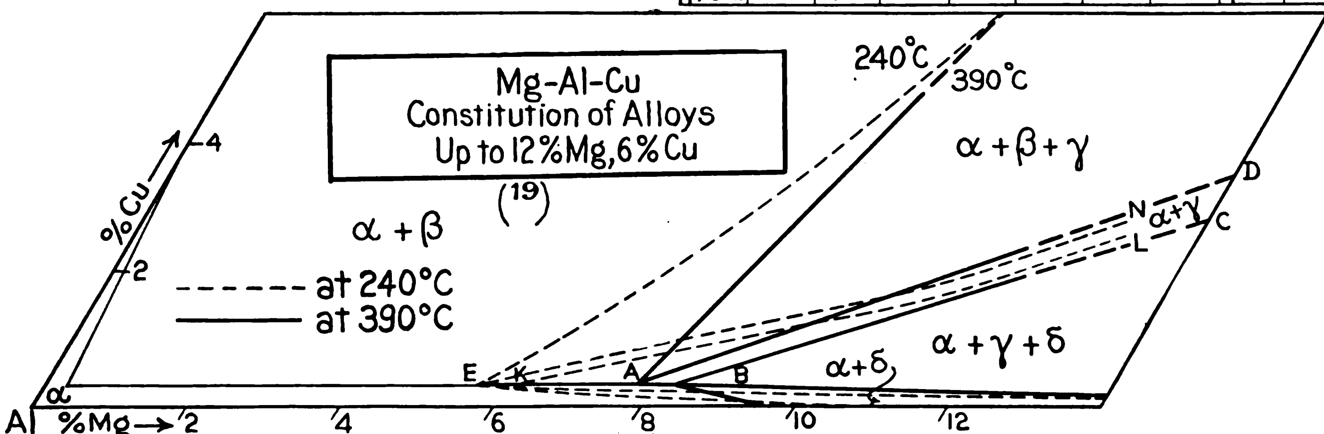

1800°C
1710°
1600°
Al-Pt
(10)
1400°
?
1200°
70
1000°
Al3 Pt
+
Liq.
?
Liq.
800°
40
788°
?
657°
9
639°
600°
548°
% Pt → 20 40 60 80

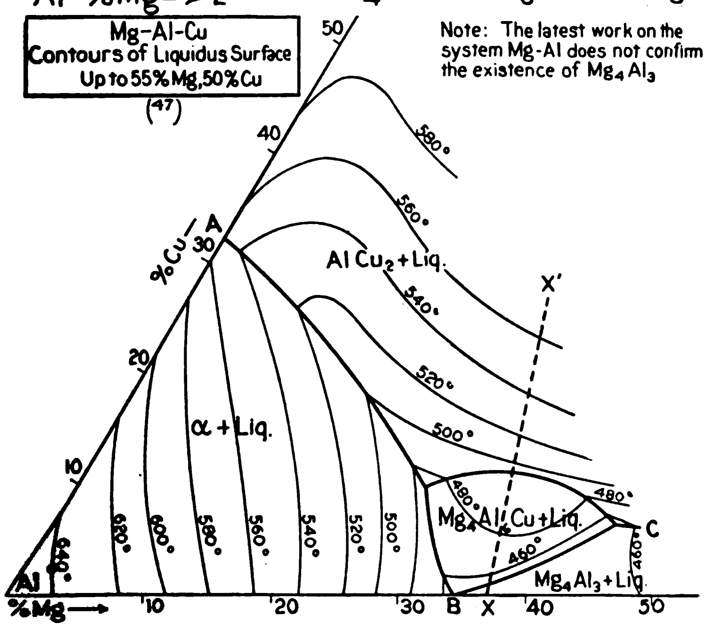

1400°C
1410°
Al-Si
(14, 17, 37)
1200°
1000°
Si + Liq.
Liq.
800°
652°
11.2
577°
Al + Si
% Si → 20 40 60 80


657°
600°C
Liq.
500°
Al + Liq.
Al-Sn
(21)
400°
300°
232°
Al + Sn
% Sn → 20 40 60 80

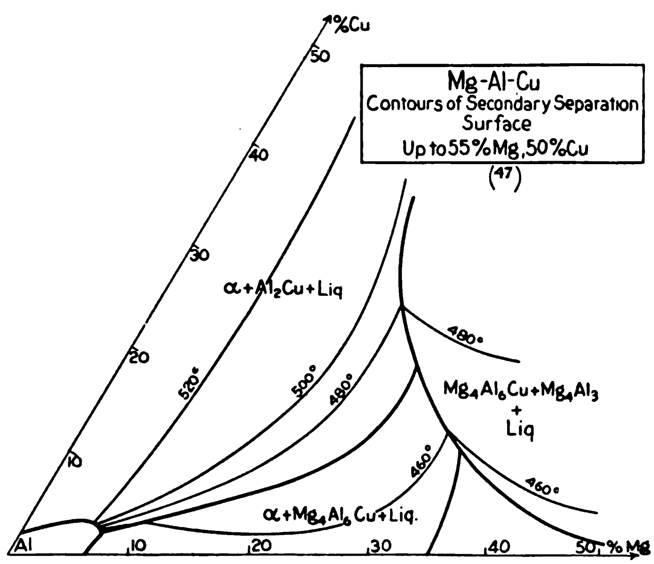


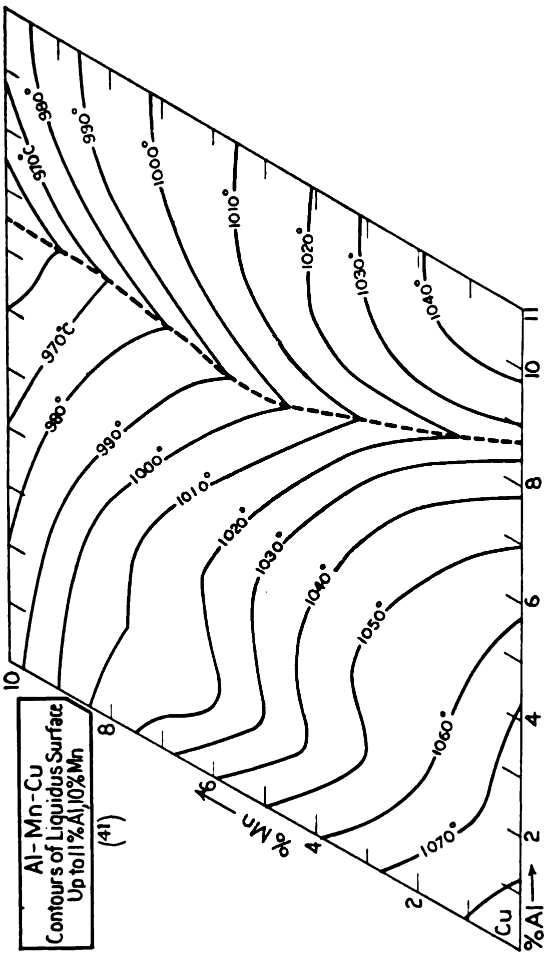


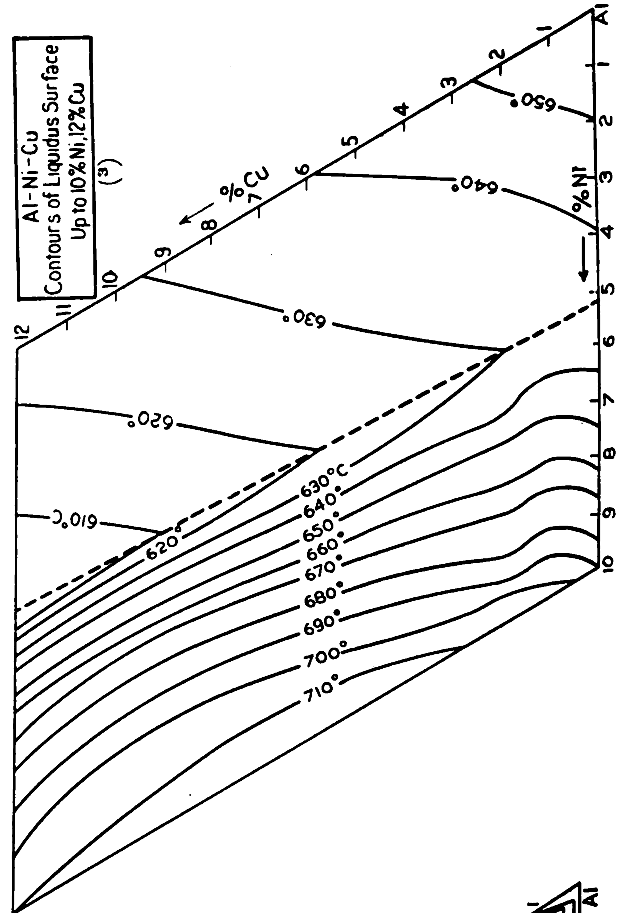


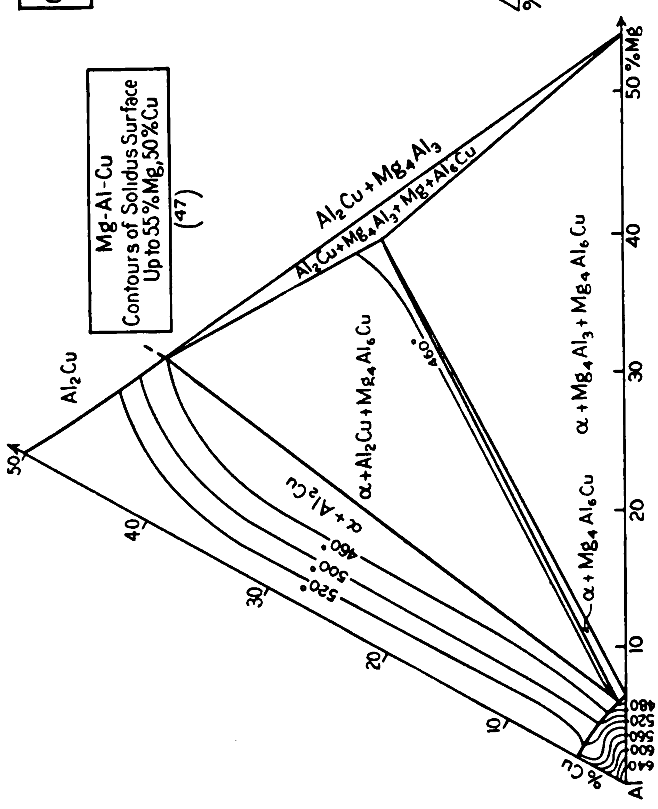


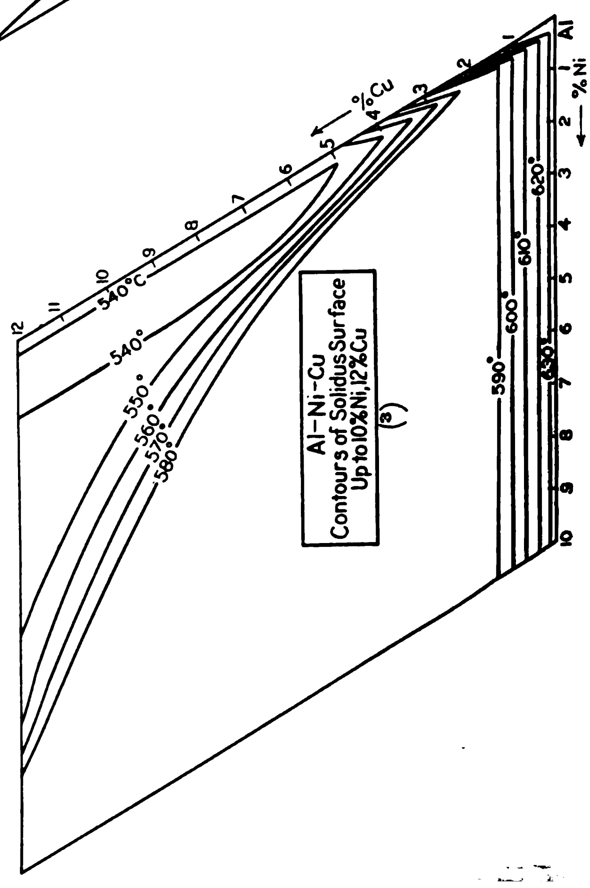
Note: The latest work on the system Mg-Al does not confirm the existence of Mg_4Al_3

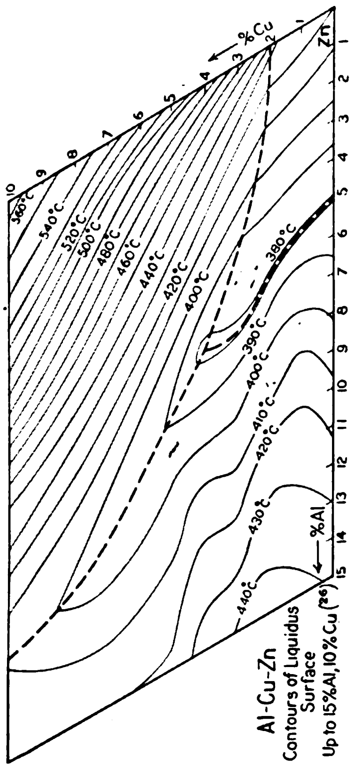



Al-Mn-Cu
Contours of Liquidus Surface
Up to 11% Al, 10% Mn
(41)

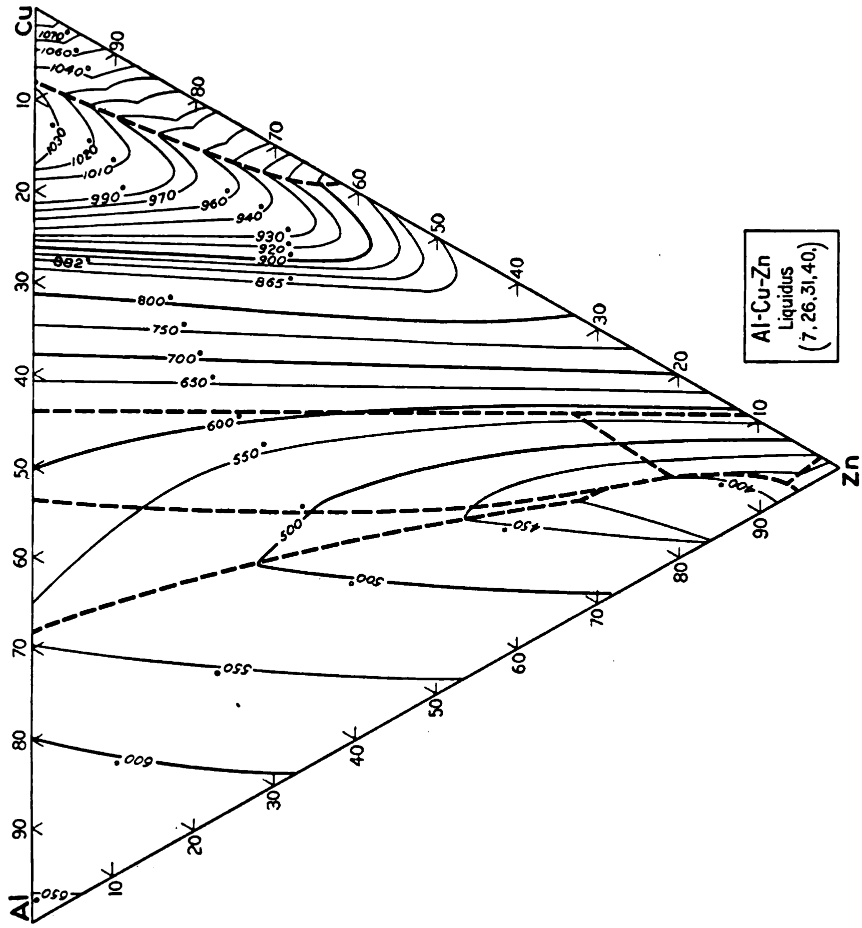

Al-Ni-Cu
Contours of Liquidus Surface
Up to 10% Ni, 12% Cu
(3)


Mg-Al-Cu
Contours of Solidus Surface
Up to 55% Mg, 50% Cu
(47)

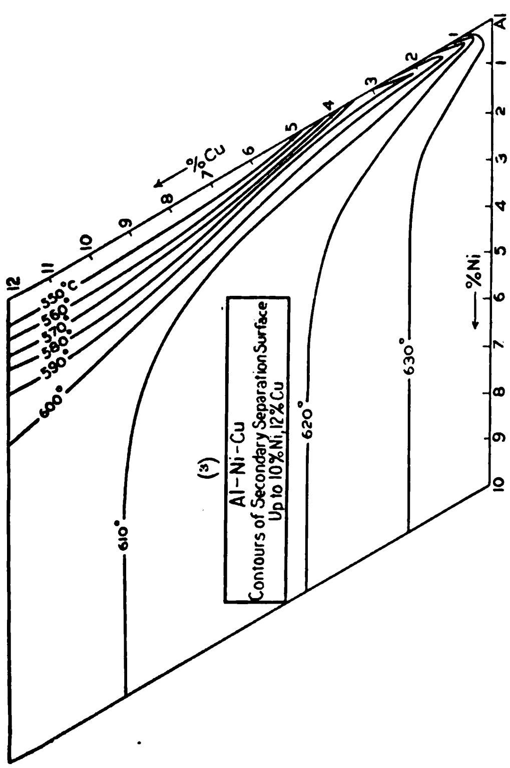

Al-Ni-Cu
Contours of Solidus Surface
Up to 10% Ni, 12% Cu
(3)



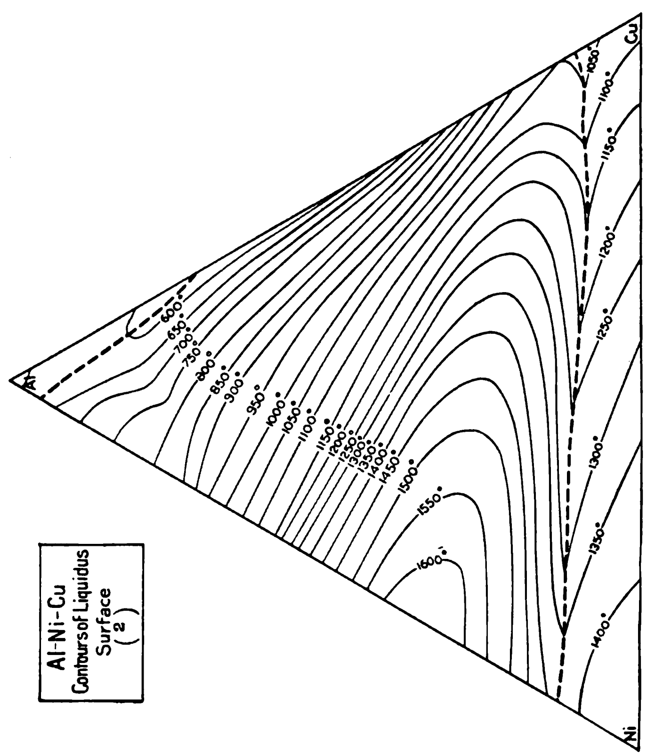
Al-Cu-Zn
Contours of Liquidus Surface
Up to 15% Al, 10% Cu (26)



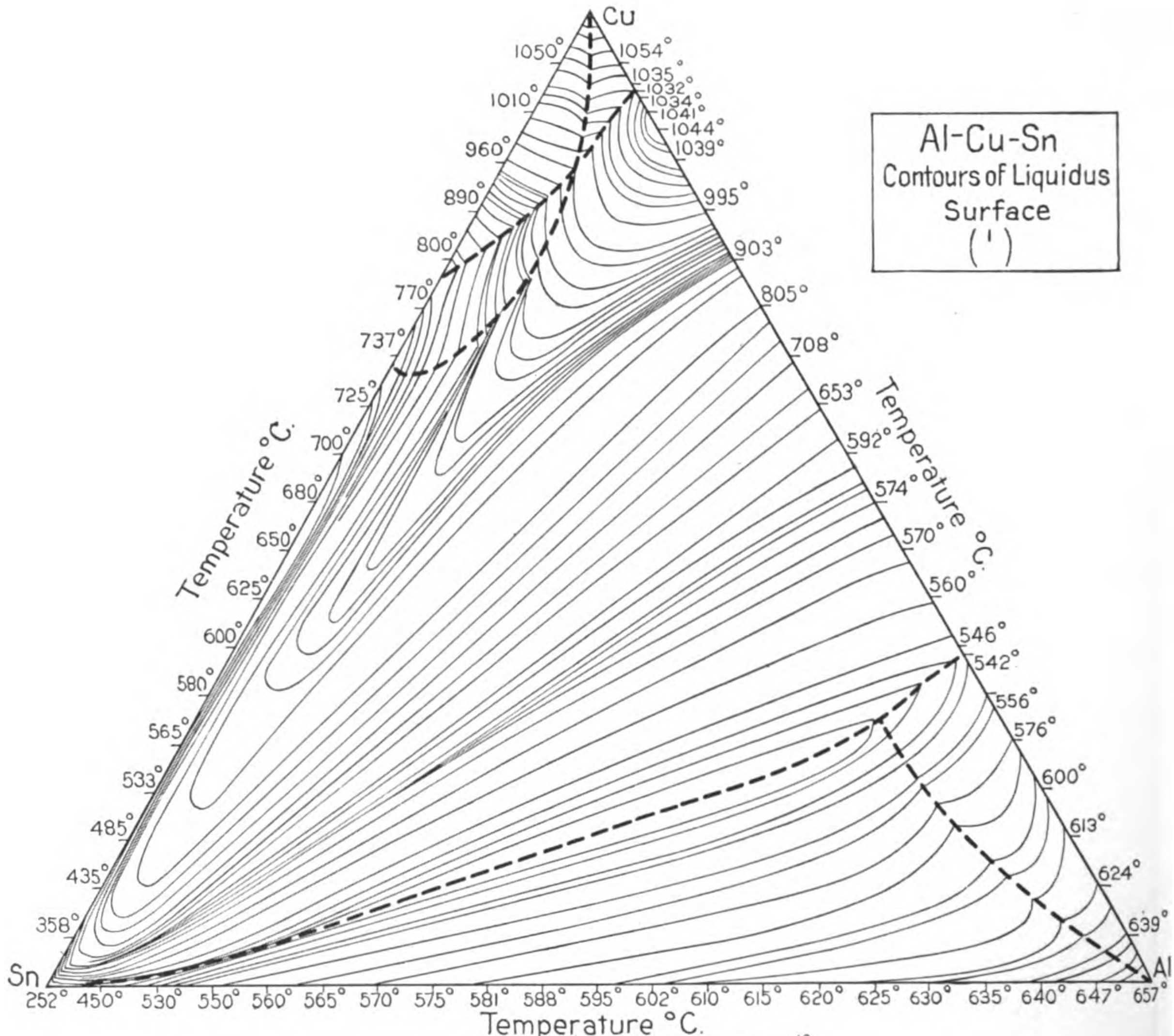
Al-Cu-Zn
Liquidus
(7, 26, 31, 40.)

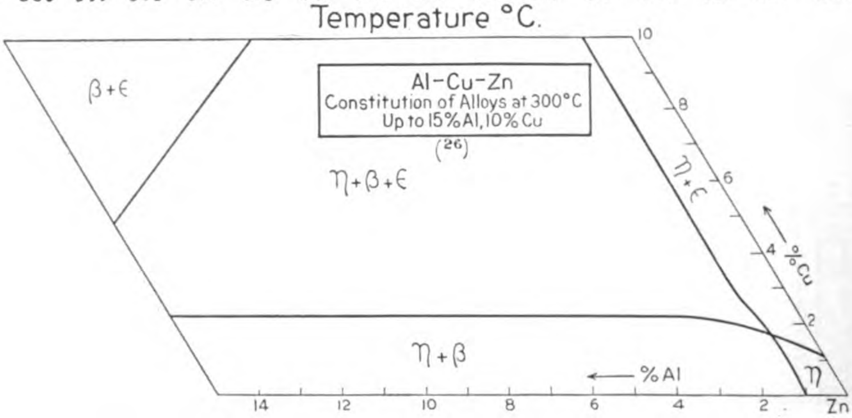


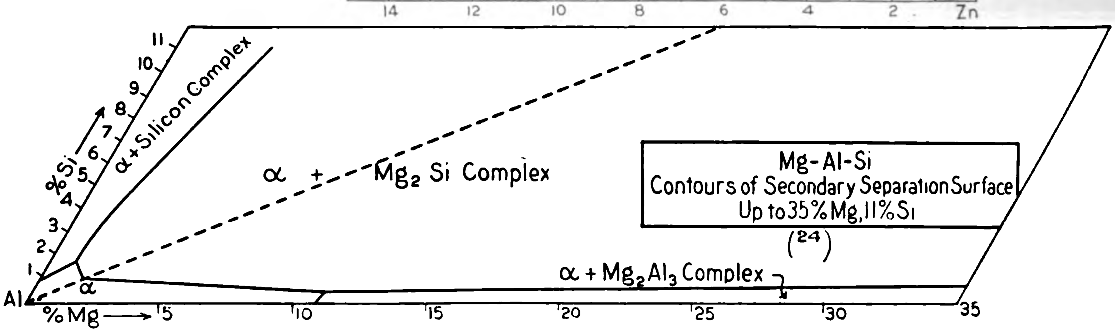
(3)
Al-Ni-Cu
Contours of Secondary Separation Surface
Up to 10% Ni, 12% Cu

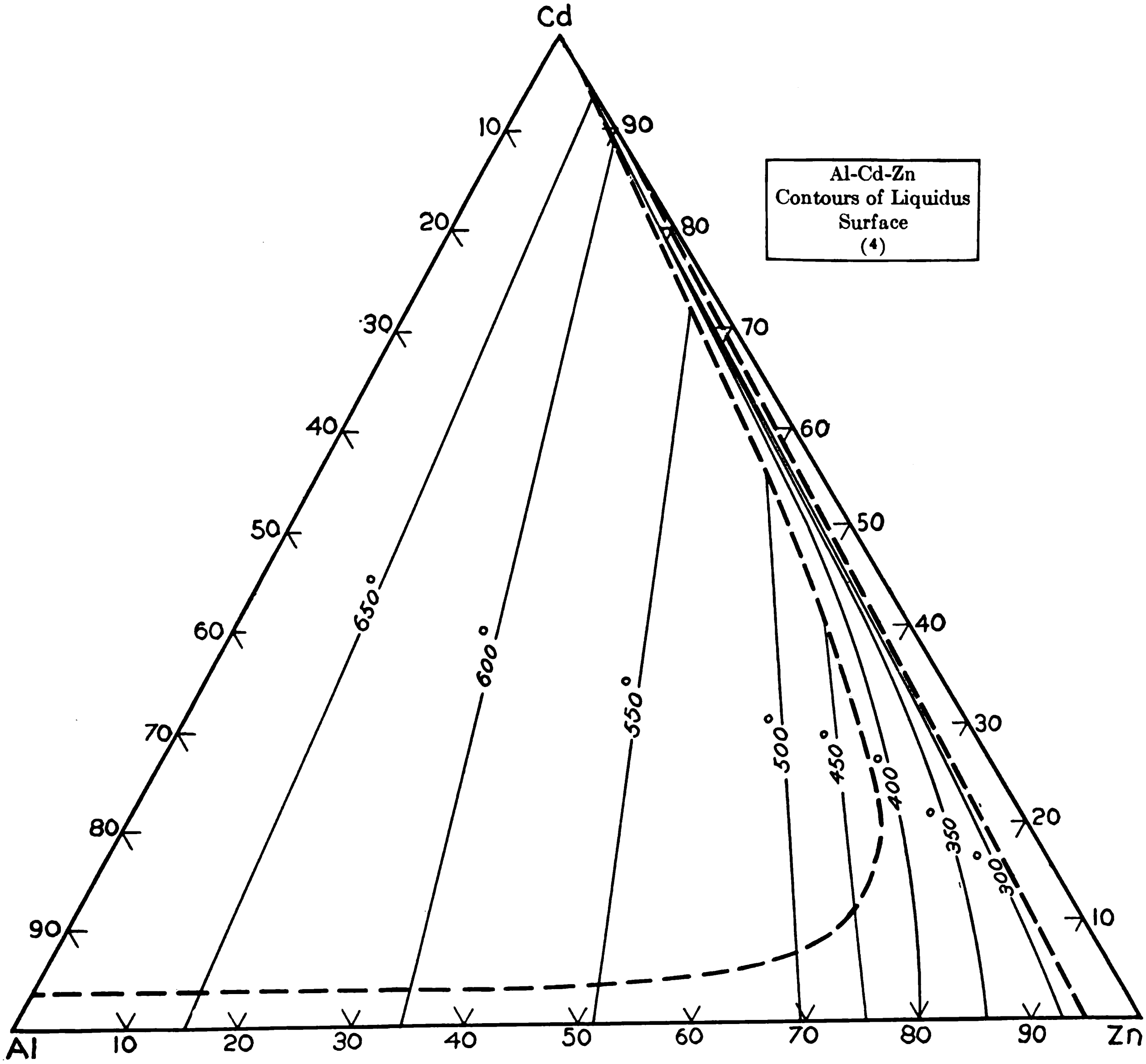


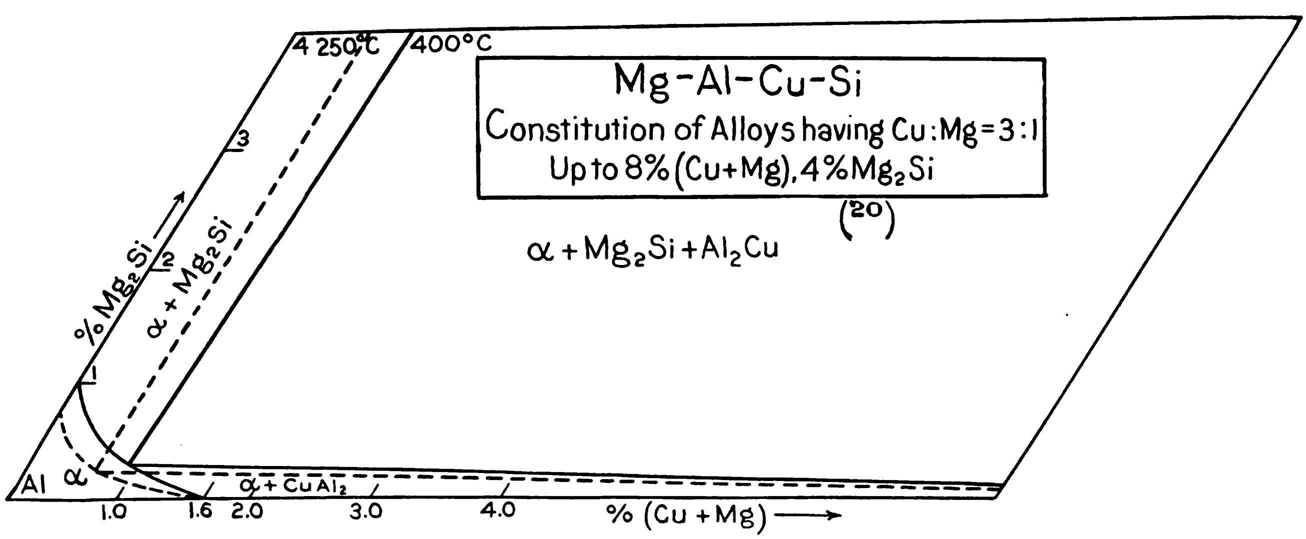
Al-Ni-Cu
Contours of Liquidus
Surface
(2)

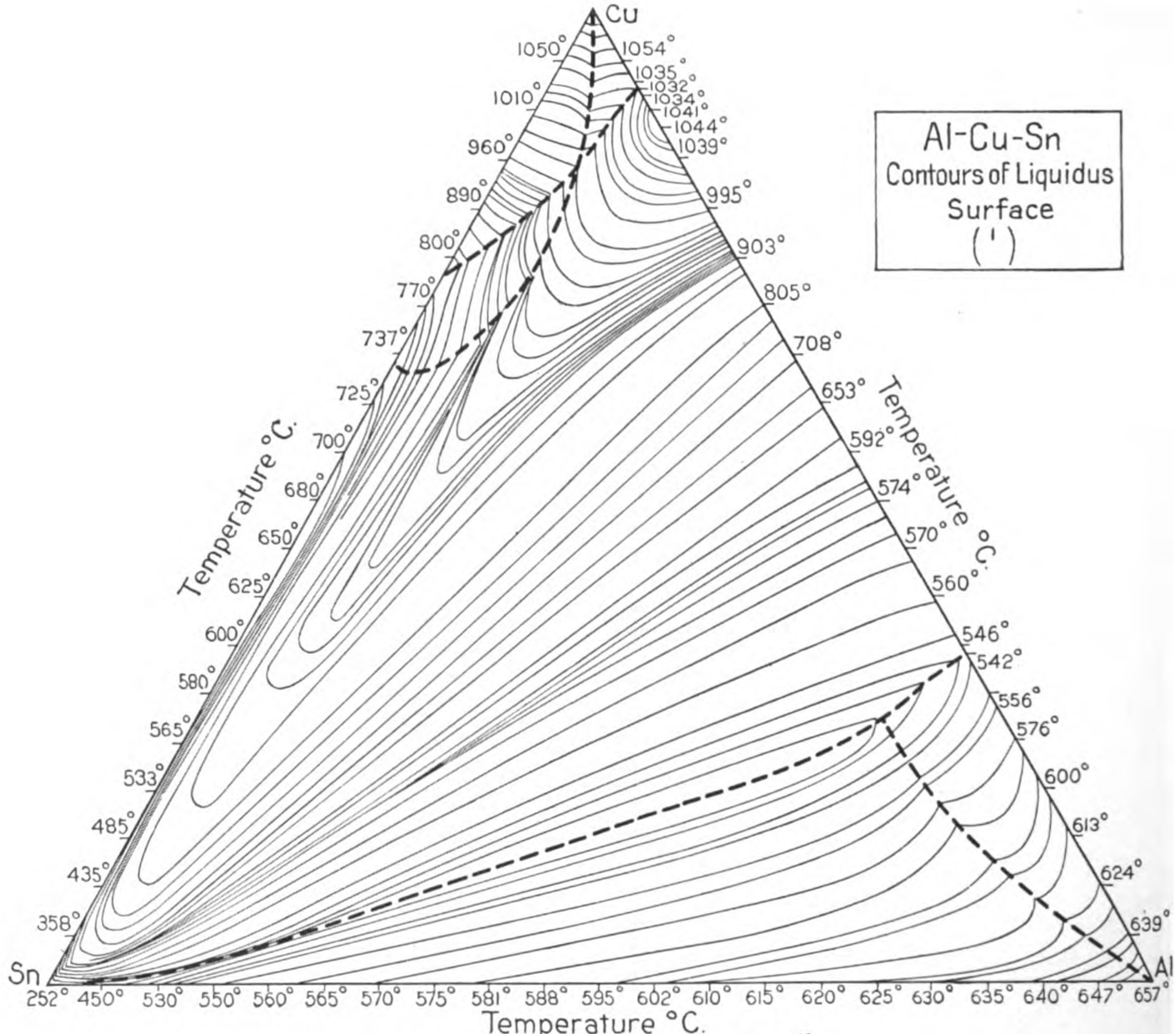

Al-Cu-Sn
Contours of Liquidus Surface
(1)
Cu
Sn
Al
Temperature °C.
Temperature °C.
Temperature °C.
1050° 1010° 960° 890° 800° 770° 737° 725° 700° 680° 650° 625° 600° 580° 565° 533° 485° 435° 358°
1054° 1035° 1032° 1034° 1041° 1044° 1039° 995° 903° 805° 708° 653° 592° 574° 570° 560° 546° 542° 556° 576° 600° 613° 624° 639°
252° 450° 530° 550° 560° 565° 570° 575° 581° 588° 595° 602° 610° 615° 620° 625° 630° 635° 640° 647° 657°


Al-Cu-Zn
Constitution of Alloys at 300°C
Up to 15% Al, 10% Cu
(26)
β+ϵ
η+β+ϵ
η+ϵ
η+β
η
%Cu
%Al
14 12 10 8 6 4 2 Zn
10 8 6 4 2

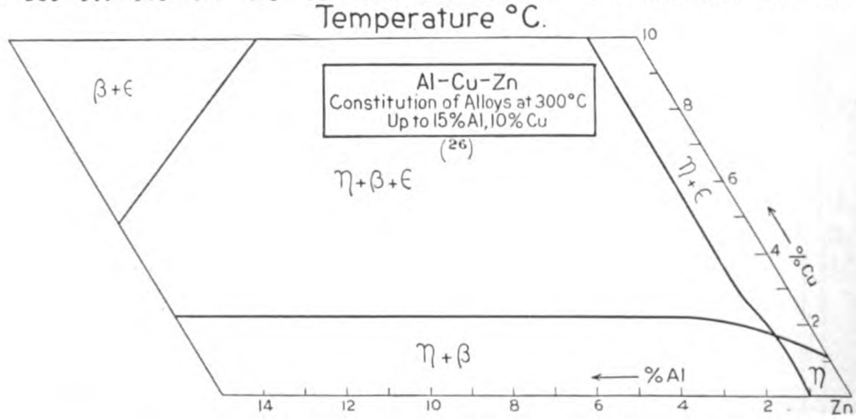

Mg-Al-Si
Contours of Secondary Separation Surface
Up to 35% Mg, 11% Si
(24)
α + Silicon Complex
α + Mg₂ Si Complex
α + Mg₂Al₃ Complex
α
Al
%Si
%Mg
1 2 3 4 5 6 7 8 9 10 11
5 10 15 20 25 30 35


Cd
Al-Cd-Zn
Contours of Liquidus
Surface
(4)
650°
600°
550°
500°
450°
400°
350°
300°
Al
Zn
10
20
30
40
50
60
70
80
90

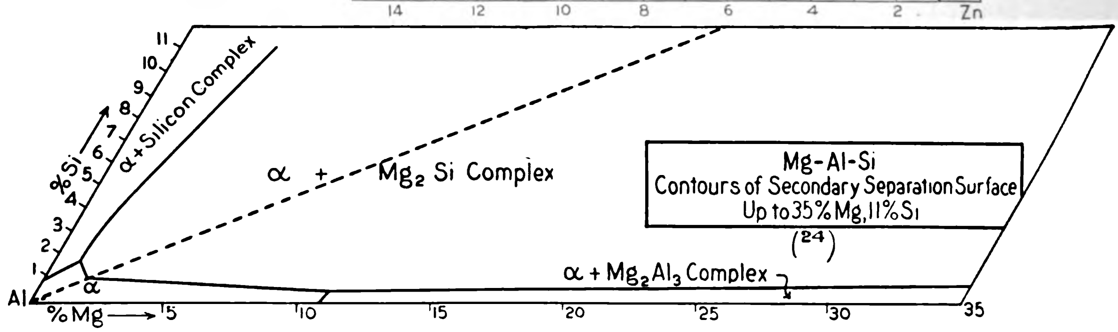

Mg-Al-Cu-Si
Constitution of Alloys having Cu:Mg = 3:1
Up to 8% (Cu+Mg), 4% Mg_2Si
(20)
4 250°C
400°C
$\alpha + Mg_2Si + Al_2Cu$
% Mg_2Si
$\alpha + Mg_2Si$
$\alpha + CuAl_2$
Al
α
1.0
1.6
2.0
3.0
4.0
% (Cu + Mg)



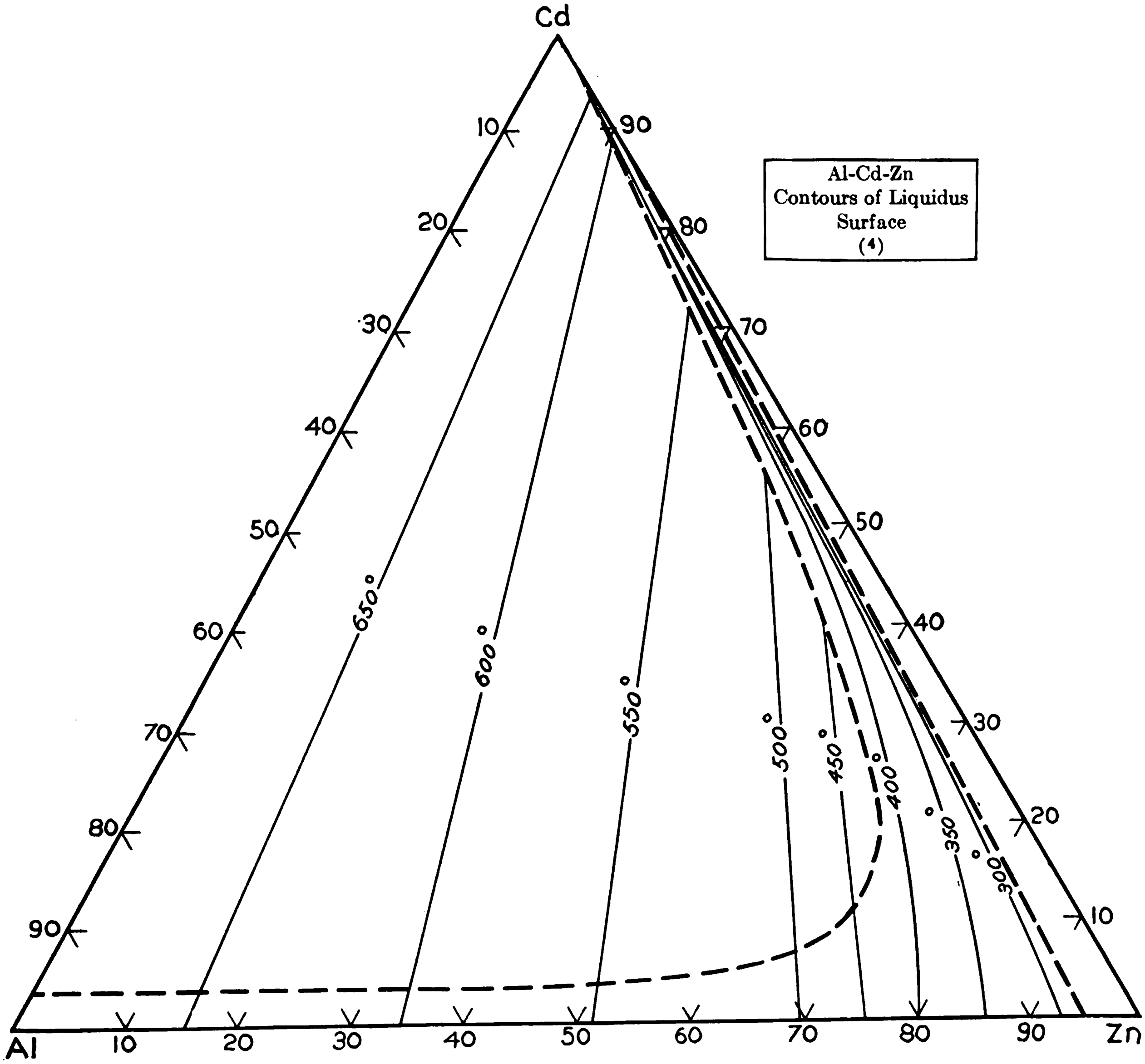
Al-Cu-Sn
Contours of Liquidus Surface
(1)

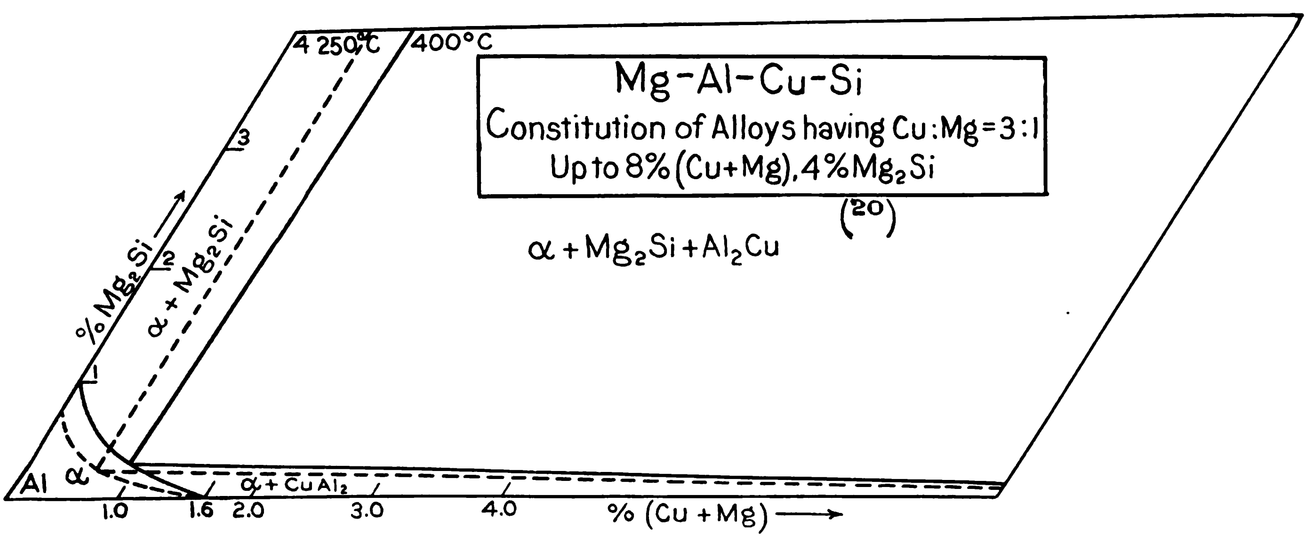


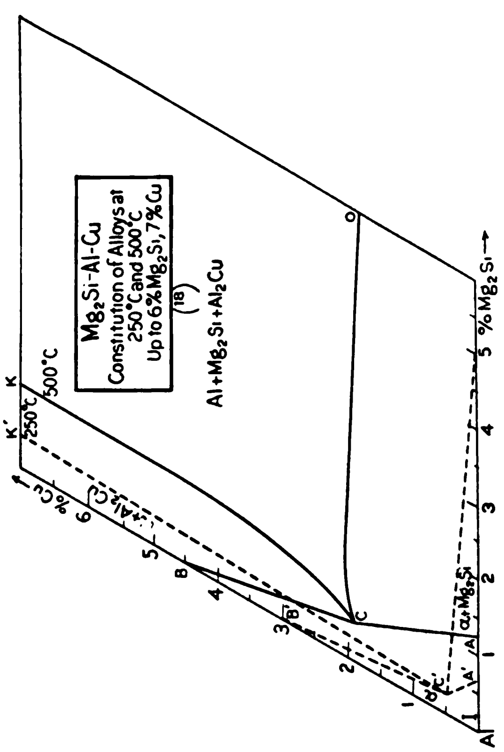
Al-Cu-Zn
Constitution of Alloys at 300°C
Up to 15% Al, 10% Cu
(26)

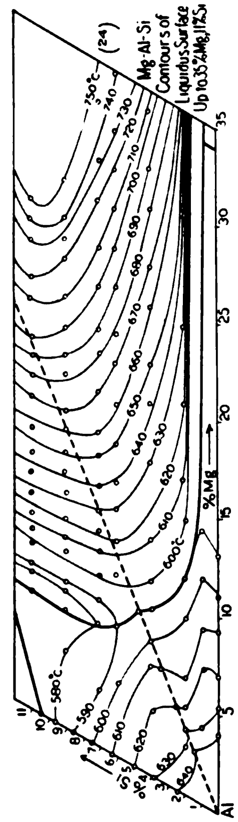


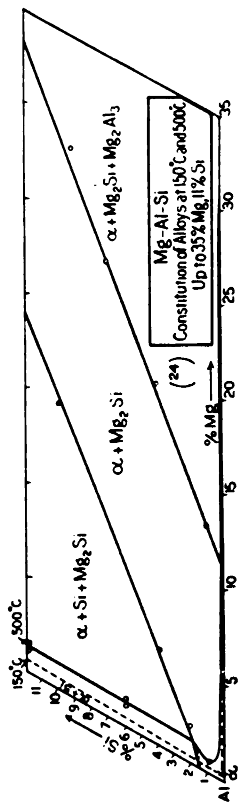
Mg-Al-Si
Contours of Secondary Separation Surface
Up to 35% Mg, 11% Si
(24)

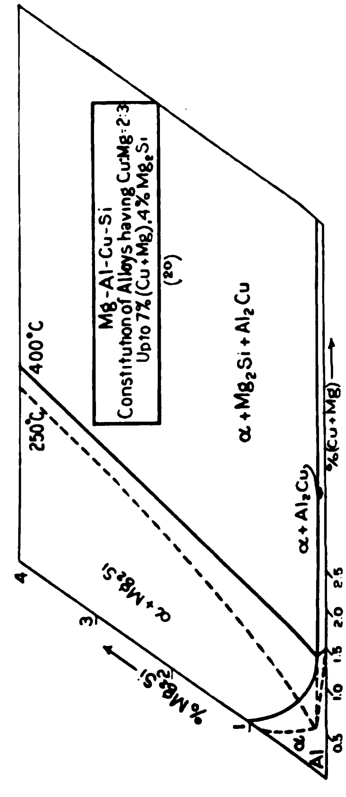

Cd
Al
Zn
Al-Cd-Zn
Contours of Liquidus
Surface
(4)
650°
600°
550°
500°
450°
400°
350°
300°
10
20
30
40
50
60
70
80
90

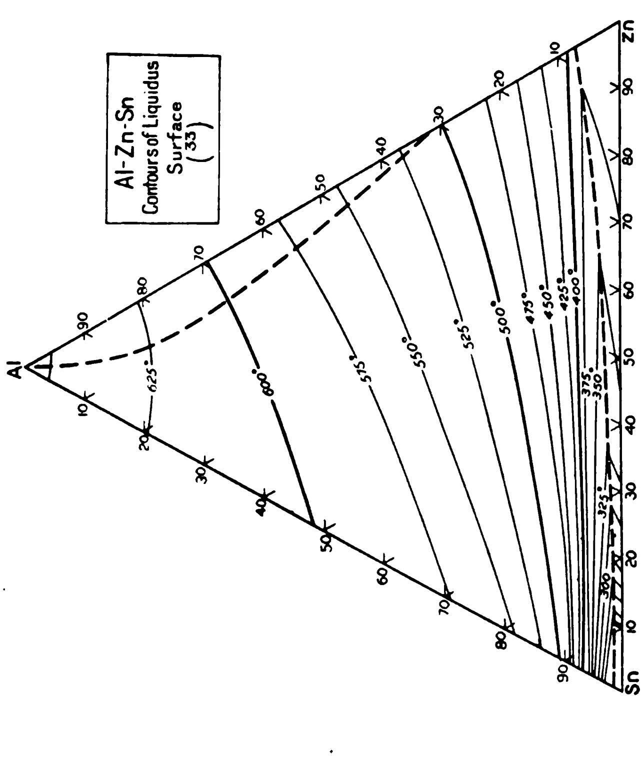

Mg-Al-Cu-Si
Constitution of Alloys having Cu:Mg=3:1
Up to 8% (Cu+Mg), 4% Mg₂Si
(20)
α + Mg₂Si + Al₂Cu
α + Mg₂Si
% Mg₂Si
250°C
400°C
α
α + CuAl₂
Al
1.0
1.6
2.0
3.0
4.0
% (Cu+Mg)







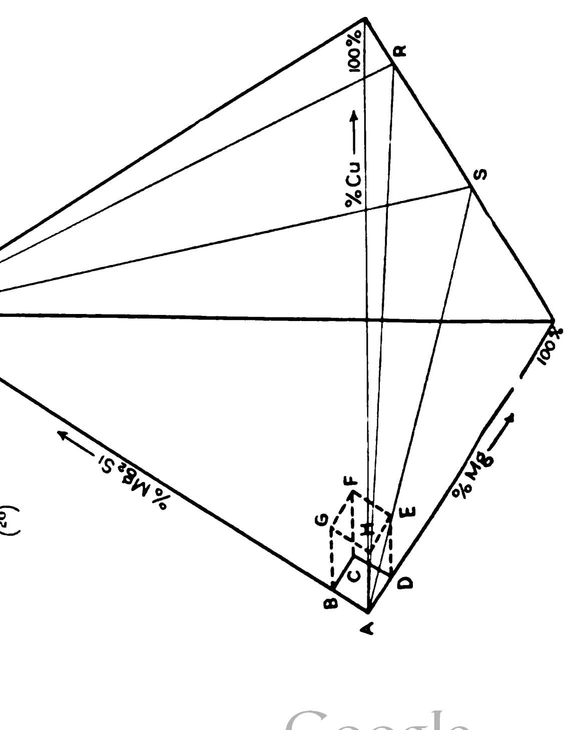


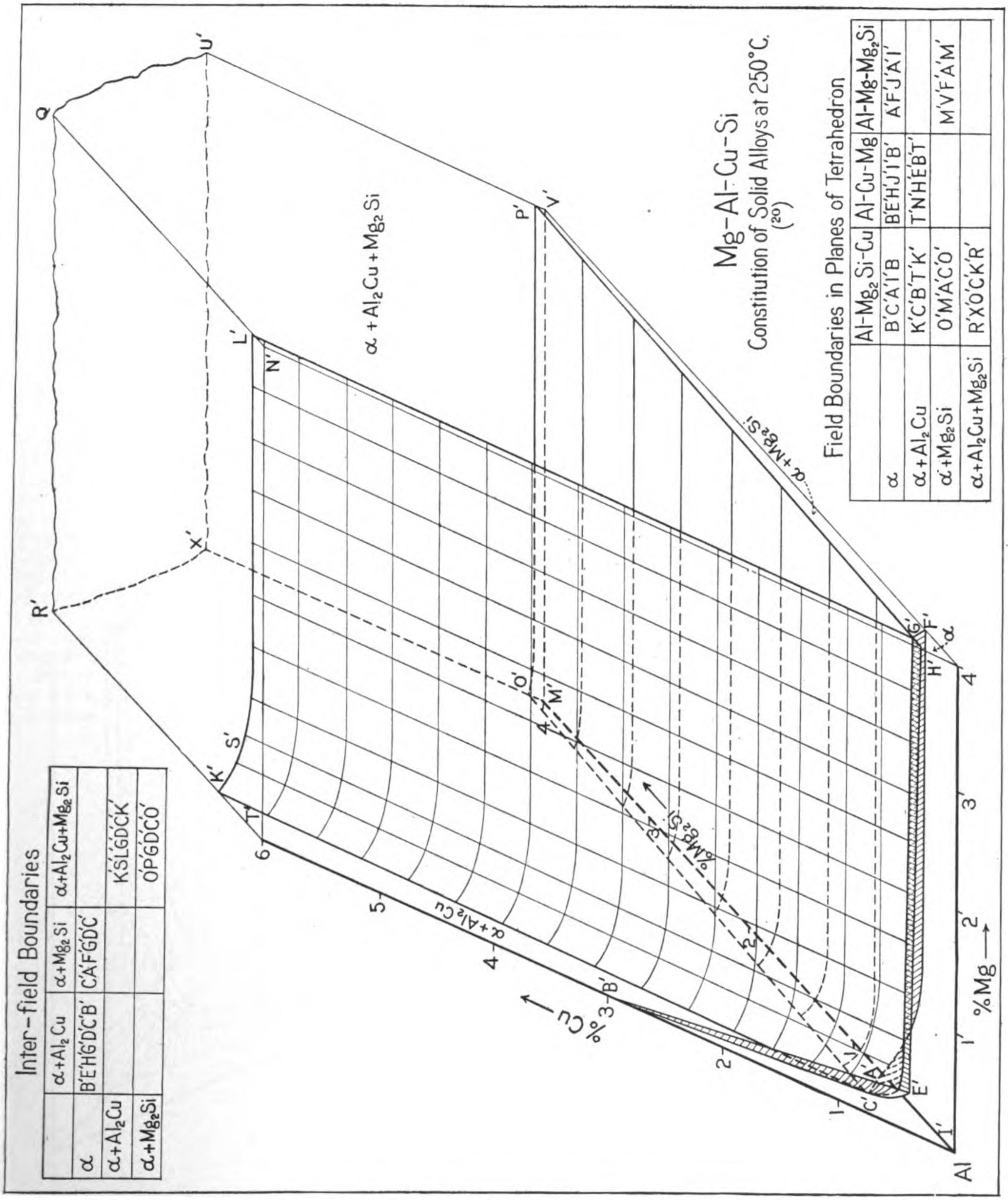


Mg-Al-Cu-Si

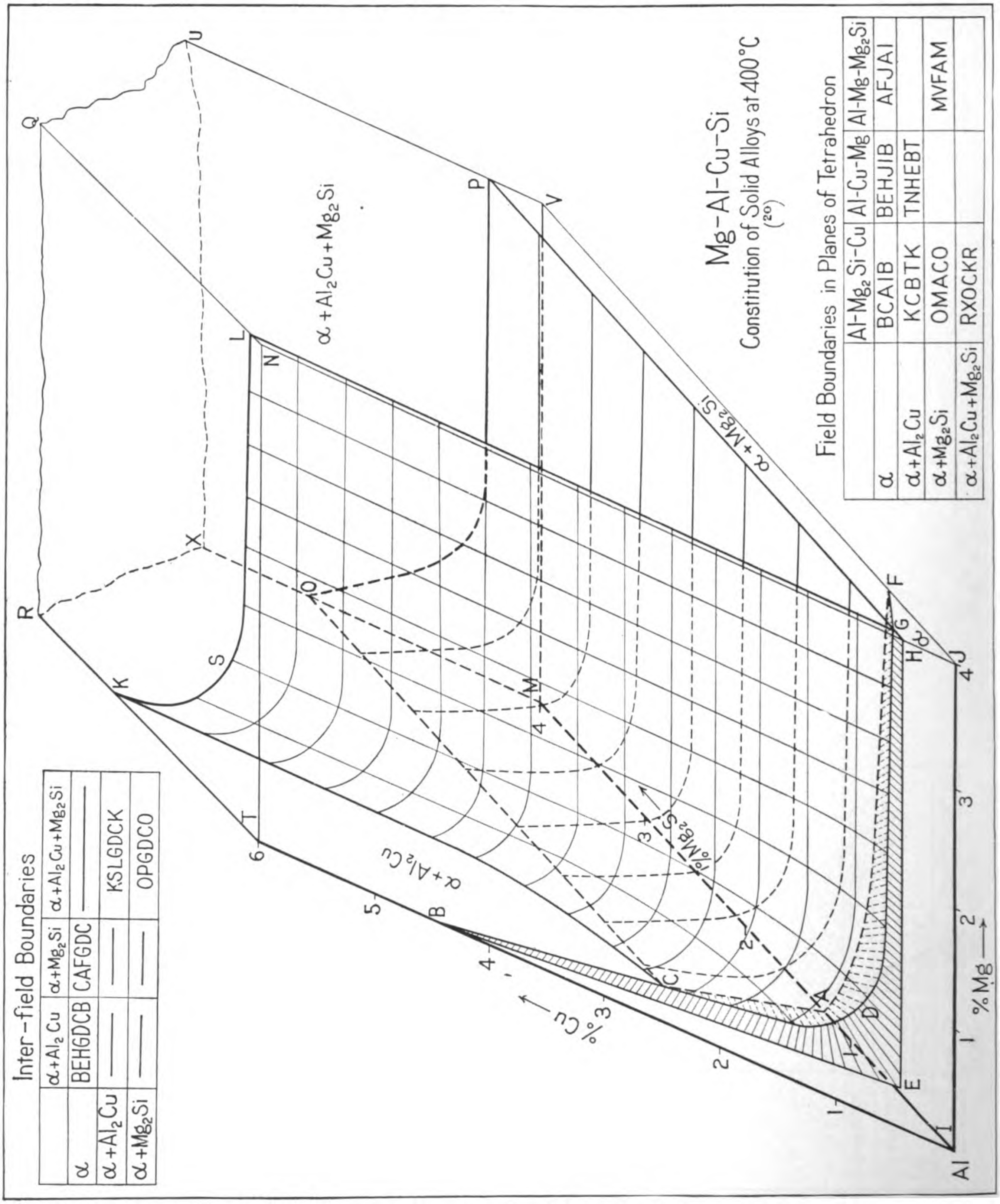
Typical Isotherm showing Composition of Alloys investigated up to 4% Mg, 4% Mg$_2$Si, 6% Cu

(20)





Note:—Point J' is at 4 % Mg.



NOTE:—Point B should be at 4 % Cu.

LEAD ALLOYS AND TIN ALLOYS

O. F. Hudson

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LITERATURE

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(1) Baar, *93*, **70**: 352; 11. (2) Bogitch, *34*, **159**: 178; 15. (3) Budgen, *Cadmium, Its Metallurgy, Properties and Uses.* London, Griffin, 1924. (4) Dean, Hudson and Fogler, *45*, **17**: 1246; 25. (5) Di Capua, *36*, **55**: 280; 25. (6) Doerinckel, *93*, **54**: 333; 07. (7) Fay and Gillson, *80*, **31**: 527; 01. (8) Fischer, *97*, **6**: 146; 25. (9) Friedrich, *192*, **3**: 396; 06.

(10) Fuchs, *93*, **107**: 308; 19. (11) Gontermann, *93*, **55**: 419; 07. (12) Grube, *93*, **44**: 117; 05. (13) Grube, *93*, **46**: 76; 05. (14) Guertler, *Metallography.* Berlin, Gebröder Borntraeger, 1910. (15) Heike, *95*, **6**: 49; 14. (16) Herold, *93*, **112**: 131; 20. (17) van Heteren, *93*, **42**: 129; 04. (18) Heycock and Neville, *4*, **72**: 383; 97. (19) Hindricks, *93*, **59**: 414; 08.

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(30) Masing and Tammann, *93*, **67**: 183; 10. (31) Mathewson, *93*, **50**: 171; 06. (32) Mazzotto, *95*, **4**: 273; 13. (33) Muzaffar, *4*, **123**: 2341; 23. (34) Niclassen, *Forschungsarbeiten zur Metallkunde*, **7**: 9; 22. (35) Parravano, Mazzetti and Moretti, *36*, **44** II: 475; 14. (36) Petrenko, *93*, **53**: 200; 07. (37) Rosenhain and Tucker, *5*, **81**: 331; 08. (38) Ruer, *93*, **52**: 345; 07. (39) Shepherd, *50*, **6**: 519; 02.

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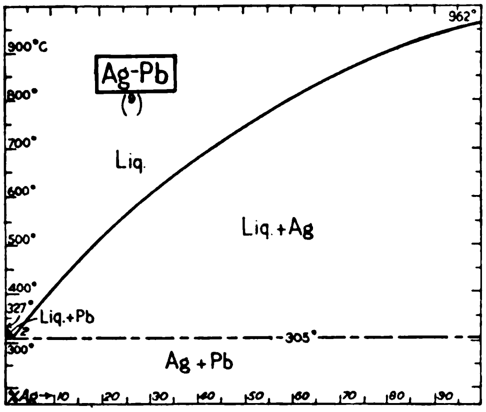
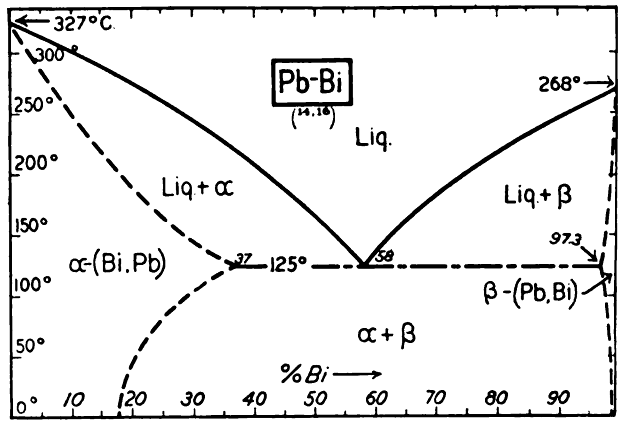
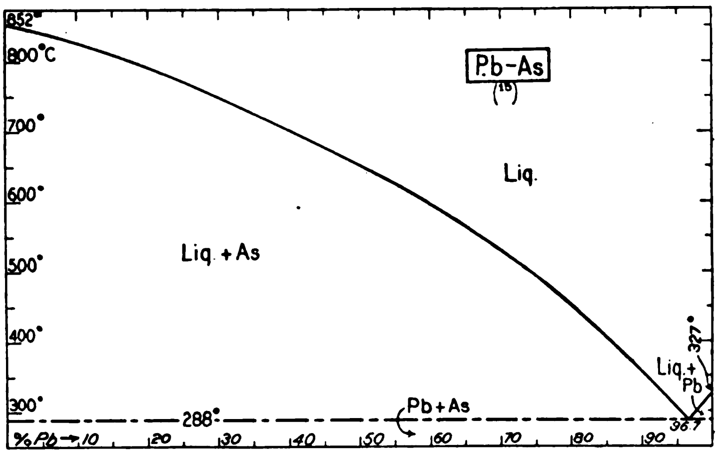
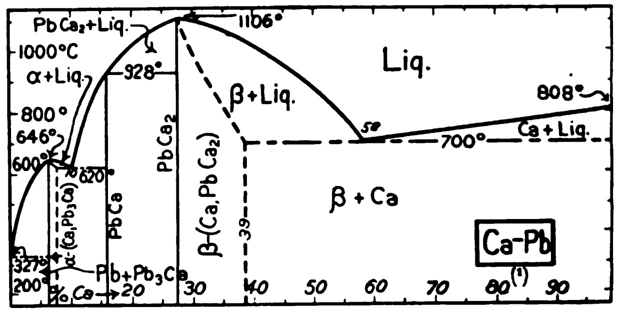
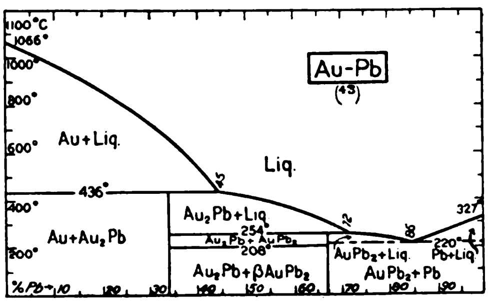
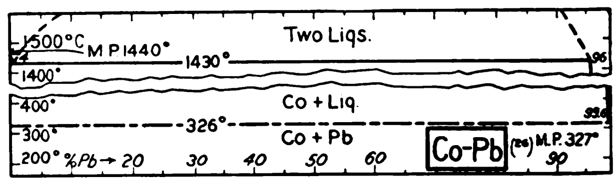

Ag-Pb
962°
900°C
800°
700°
600°
500°
400°
327°
300°
Liq.
Liq.+Ag
Liq.+Pb
305°
Ag+Pb
%Ag→10 20 30 40 50 60 70 80 90

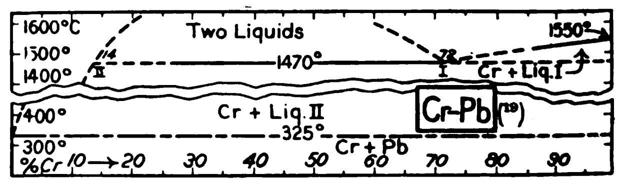

Pb-Bi
(14,16)
327°C
300°
250°
200°
150°
100°
50°
0°
268°
Liq.
Liq.+α
Liq.+β
97.3
37
125°
58
α-(Bi,Pb)
β-(Pb,Bi)
α+β
%Bi→
10 20 30 40 50 60 70 80 90

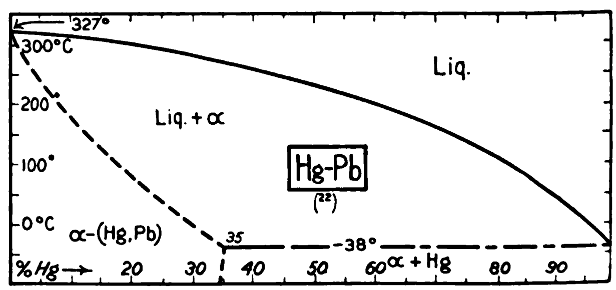

Pb-As
852°
800°C
700°
600°
500°
400°
300°
Liq.
Liq.+As
Liq.+Pb
327°
288°
Pb+As
%Pb→10 20 30 40 50 60 70 80 90
96.7

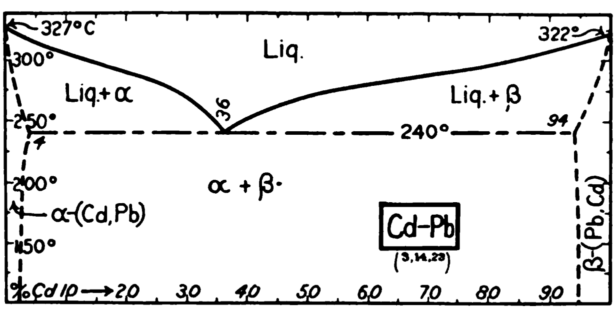

PbCa₂+Liq.
1106°
1000°C
α+Liq.
328°
800°
646°
600°
620°
327°
200°
β+Liq.
Liq.
808°
58
700°
Ca+Liq.
β+Ca
PbCa₂
β-(Ca,PbCa₂)
α-(Ca,Pb₃Ca)
PbCa
39
Pb+Pb₃Ca
Ca-Pb
(1)
%Ca→20 30 40 50 60 70 80 90

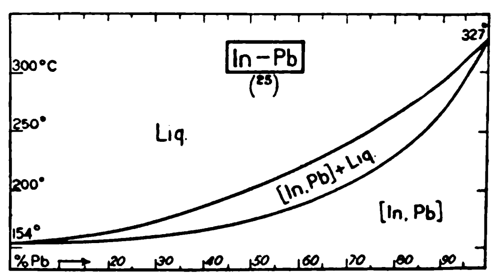

Au-Pb
(43)
1100°C
1066°
1000°
800°
600°
400°
200°
Au+Liq.
Liq.
436°
Au+Au₂Pb
Au₂Pb+Liq.
254°
Au₂Pb+AuPb₂
208°
Au₂Pb+βAuPb₂
AuPb₂+Liq.
220°
Pb+Liq.
327°
AuPb₂+Pb
%Pb→10 20 30 40 50 60 70 80 90

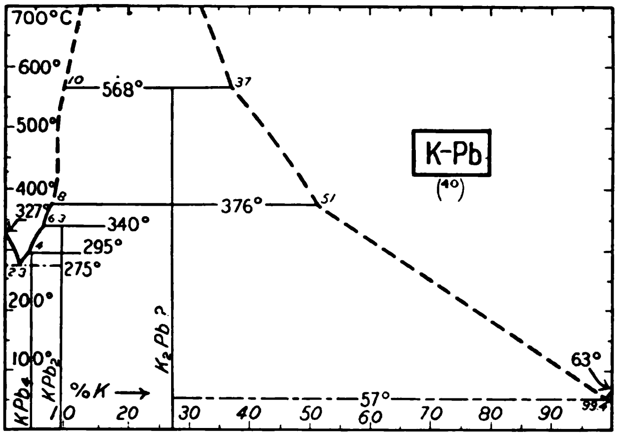

Two Liqs.
1500°C
M.P.1440°
1430°
1400°
96
400°
Co+Liq.
300°
326°
Co+Pb
200°
%Pb→20 30 40 50 60
Co-Pb
(26)
M.P. 327°
90

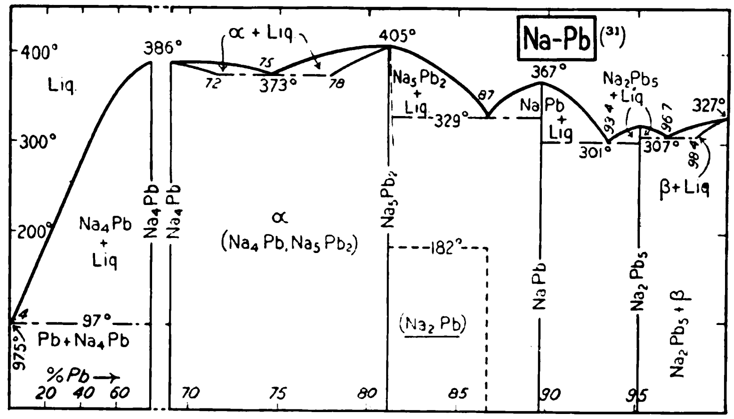

1600°C
1500°
1400°
Two Liquids
1550°
1470°
Cr+Liq.I
1400°
Cr+Liq.II
Cr-Pb
(19)
325°
300°
Cr+Pb
%Cr 10→20 30 40 50 60 70 80 90

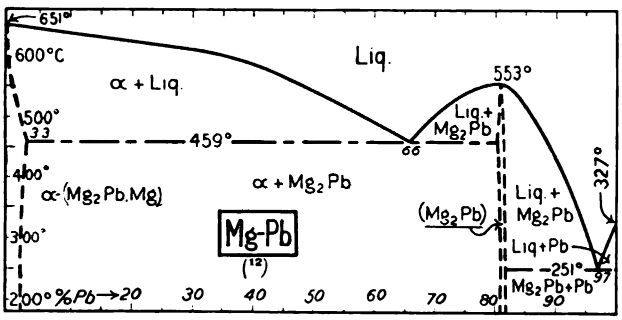

327°
300°C
200°
100°
0°C
Liq.
Liq.+α
Hg-Pb
(22)
α-(Hg,Pb)
35
-38°
α+Hg
%Hg→ 20 30 40 50 60 80 90

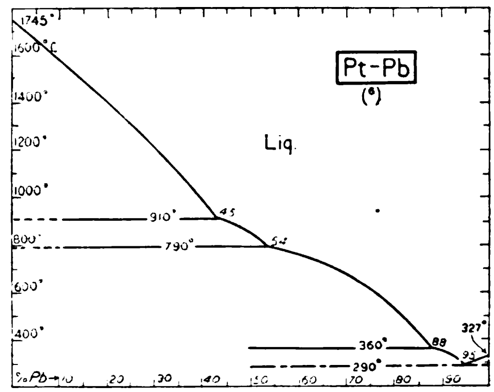

327°C
300°
322°
Liq.
Liq.+α
Liq.+β
36
250°
240°
94
200°
α+β
α-(Cd,Pb)
150°
Cd-Pb
(3,14,23)
β-(Pb,Cd)
%Cd 10→20 30 40 50 60 70 80 90

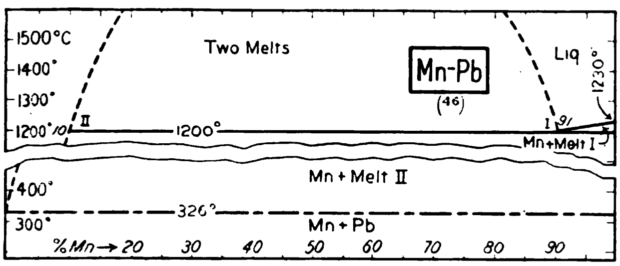

In-Pb
(25)
327°
300°C
250°
Liq.
200°
[In,Pb]+Liq.
[In,Pb]
154°
%Pb→ 20 30 40 50 60 70 80 90

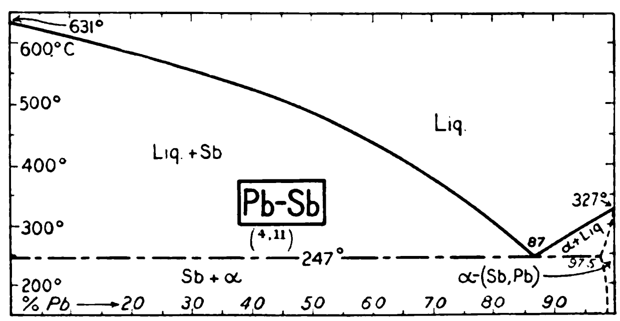


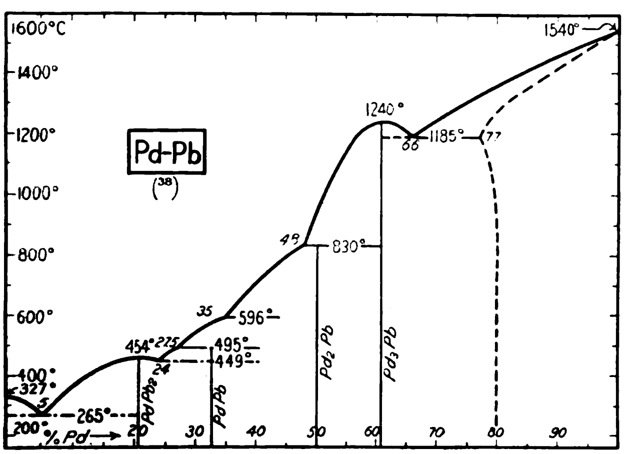


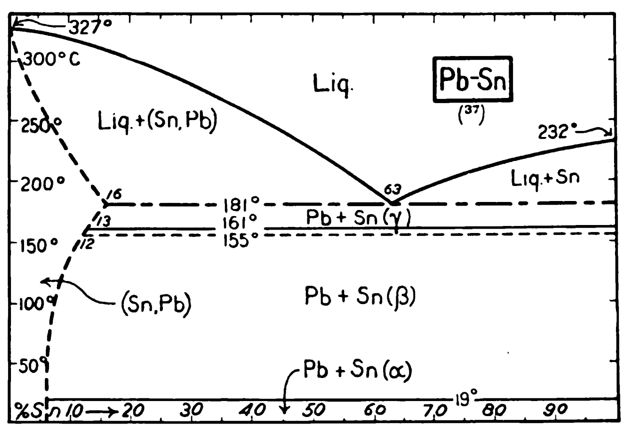












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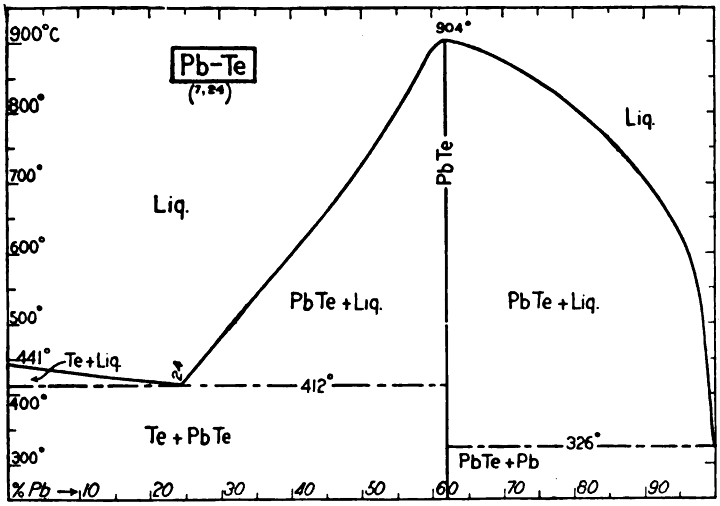
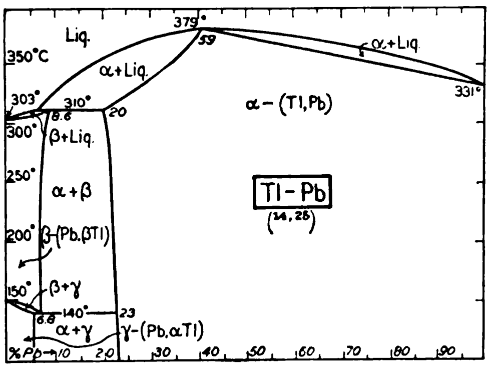
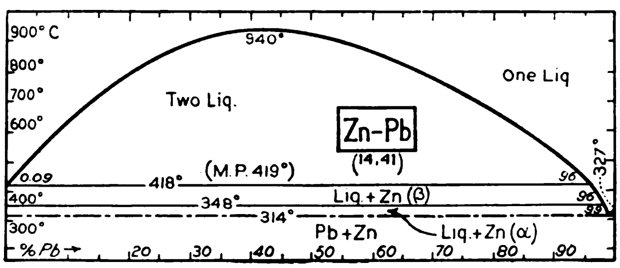
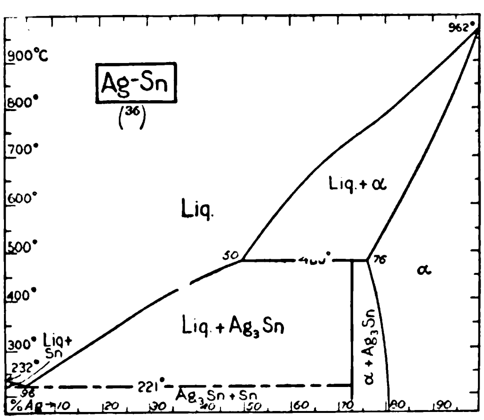
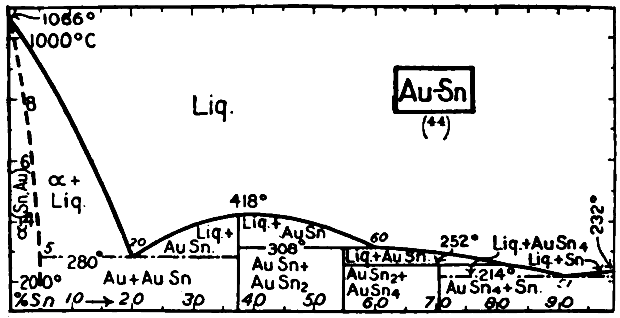
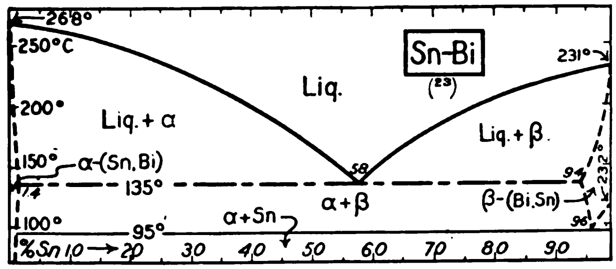

Pb-Te
(7, 24)
900°C
800°
700°
600°
500°
441°
400°
300°
904°
PbTe
Liq.
Liq.
Te + Liq.
412°
PbTe + Liq.
PbTe + Liq.
Te + PbTe
326°
PbTe + Pb
% Pb → 10 20 30 40 50 60 70 80 90

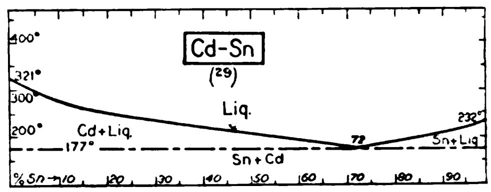

Tl-Pb
(14, 25)
Liq.
350°C
379°
59
α + Liq.
α + Liq.
303°
310°
20
331°
α - (Tl, Pb)
300°
β + Liq.
250°
α + β
200°
β-(Pb, βTl)
150°
β + γ
140°
23
α + γ
γ-(Pb, αTl)
% Pb → 10 20 30 40 50 60 70 80 90

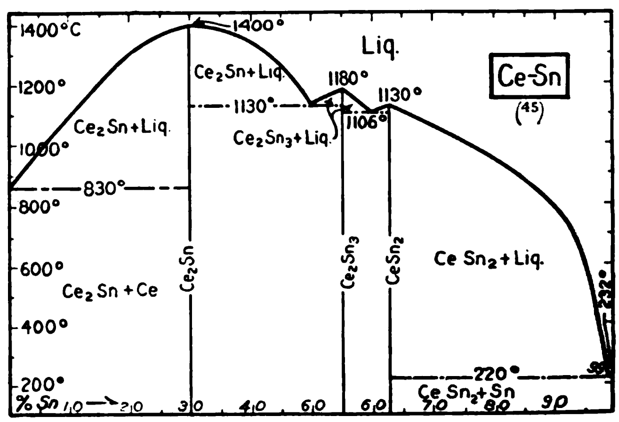

Zn-Pb
(14, 41)
900° C
800°
700°
600°
940°
Two Liq.
One Liq
0.09
418°
(M.P. 419°)
327°
400°
348°
Liq. + Zn (β)
314°
300°
Pb + Zn
Liq. + Zn (α)
% Pb → 20 30 40 50 60 70 80 90

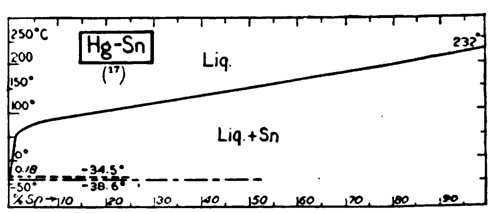

Ag-Sn
(36)
962°
900°C
800°
700°
600°
500°
400°
300°
232°
Liq.
Liq. + α
50
76
α
Liq. + Ag3Sn
α + Ag3Sn
Liq + Sn
221°
Ag3Sn + Sn
% Ag → 10 20 30 40 50 60 70 80 90

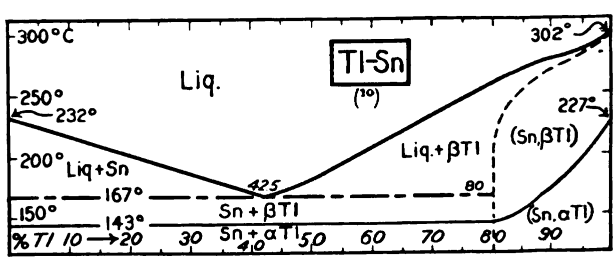

Au-Sn
(44)
1066°
1000°C
Liq.
α + Liq.
α (Sn, Au)
418°
Liq. + AuSn
Liq. + AuSn
308°
280°
Au + Au Sn
Au Sn + Au Sn2
252°
Liq. + Au Sn
Au Sn2 + Au Sn4
Liq. + AuSn4
Liq. + Sn
214°
Au Sn4 + Sn.
232°
200°
% Sn 10 → 20 30 40 50 60 70 80 90

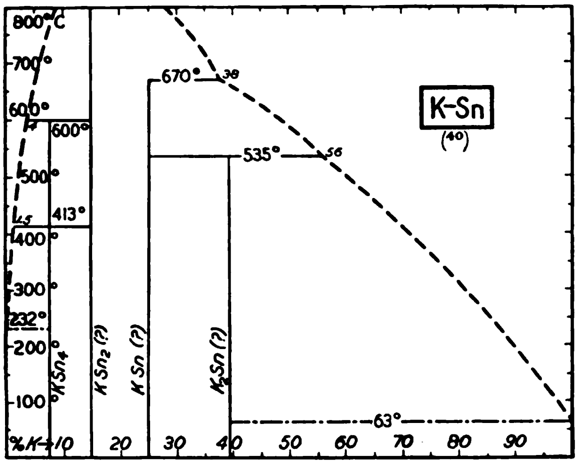

Sn-Bi
(23)
268°
250°C
231°
Liq.
200°
Liq. + α
Liq. + β.
150°
α-(Sn, Bi)
135°
59
232°
β-(Bi, Sn)
100°
95°
α + Sn
α + β
% Sn 10 → 20 30 40 50 60 70 80 90

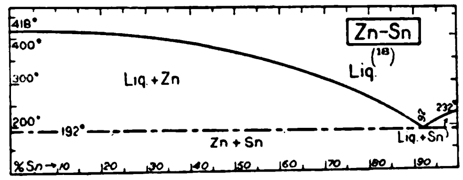

Cd-Sn
(29)
400°
321°
300°
Liq.
232°
200°
Cd + Liq.
177°
Sn + Liq
Sn + Cd
% Sn → 10 20 30 40 50 60 70 80 90

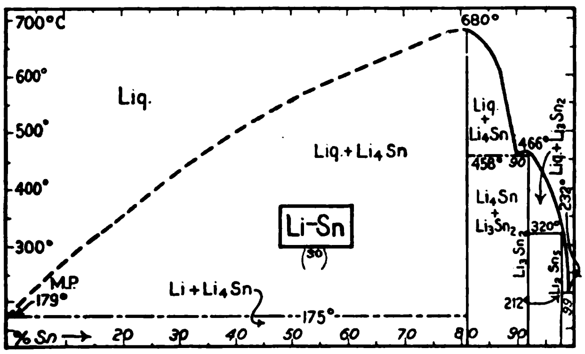

Ce-Sn
(45)
1400°C
1400°
Liq.
1200°
Ce2Sn + Liq.
1180°
1130°
1130°
1106°
Ce2Sn + Liq.
Ce2Sn3 + Liq.
1000°
830°
800°
600°
Ce2Sn
Ce2Sn3
CeSn2
Ce Sn2 + Liq.
Ce2 Sn + Ce
400°
232°
220°
200°
Ce Sn2 + Sn
% Sn 10 → 20 30 40 60 60 70 80 90

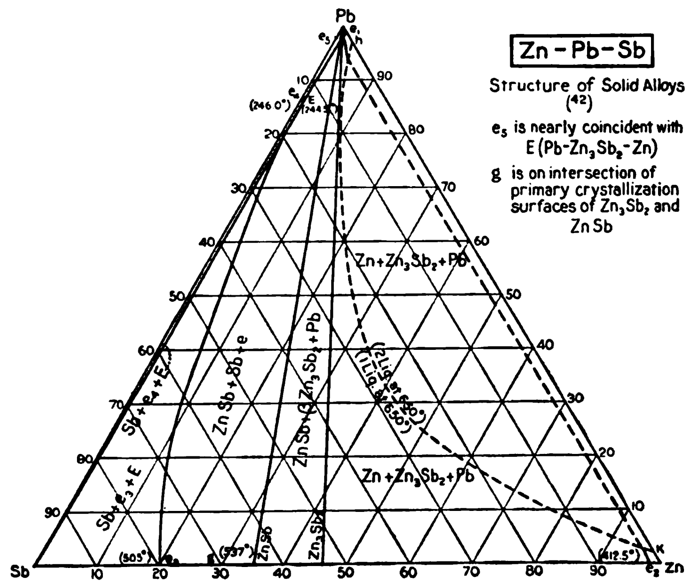

Hg-Sn
(17)
250°C
200
150°
100°
232°
Liq.
Liq. + Sn
0.18
-34.5°
-38.6°
-50°
% Sn → 10 20 30 40 50 60 70 80 90

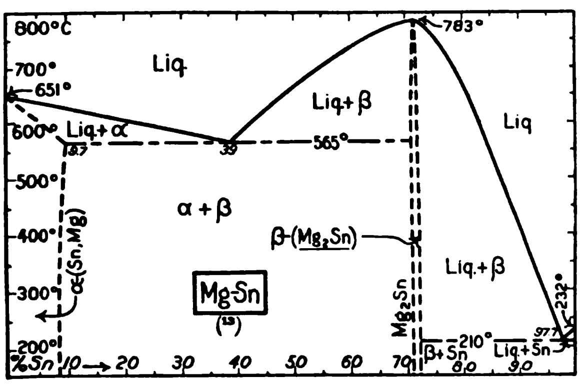

Tl-Sn
(10)
300°C
302°
Liq.
250°
232°
227°
(Sn, βTl)
200°
Liq + Sn
Liq. + βTl
167°
80
150°
143°
Sn + βTl
Sn + αTl
(Sn, αTl)
% Tl 10 → 20 30 40 50 60 70 80 90

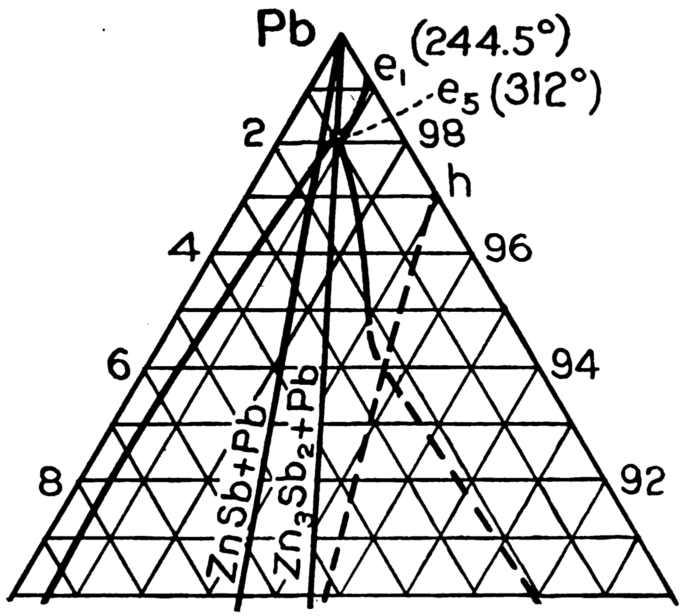




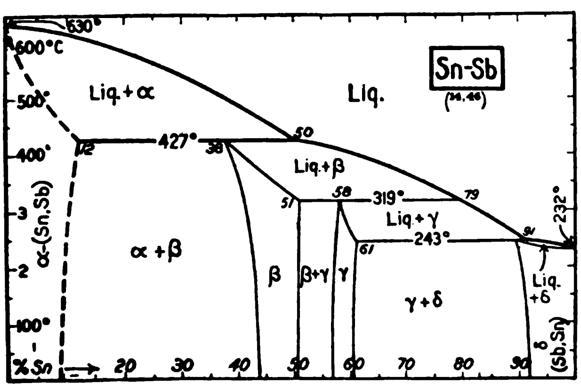


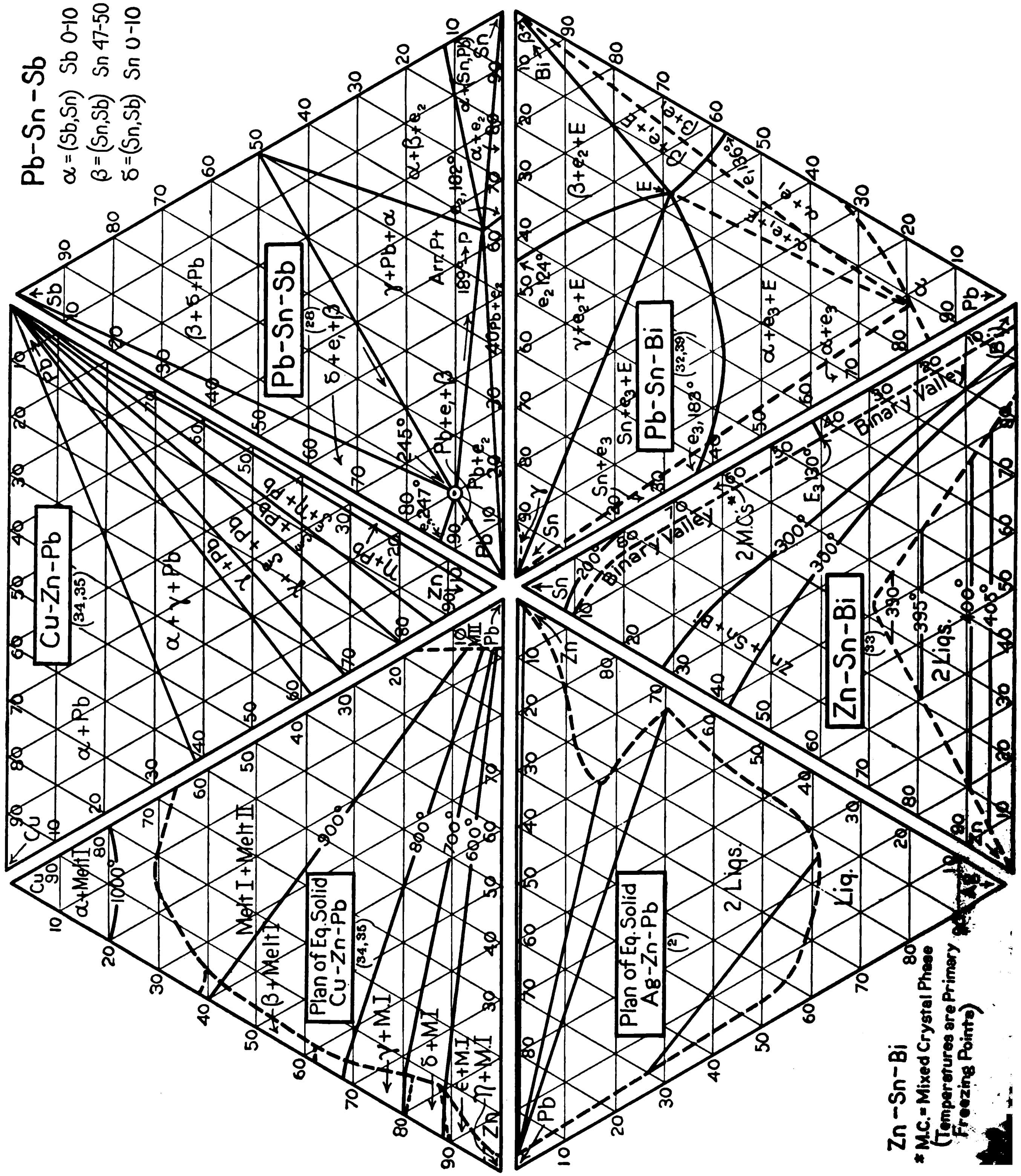






Pb corner of diagram to larger scale.




Pb-Sn-Sb
α=(Sb,Sn) Sb 0-10
β=(Sn,Sb) Sn 47-50
δ=(Sn,Sb) Sn 0-10
Pb-Sn-Sb
Pb-Sn-Bi
Zn-Sn-Bi
Cu-Zn-Pb
Plan of Eq. Solid Cu-Zn-Pb
Plan of Eq. Solid Ag-Zn-Pb
Binary Valley
2 Liqs.
Liq.
Melt I + Melt II
Zn-Sn-Bi
* M.C. = Mixed Crystal Phase
(Temperatures are Primary Freezing Points)

OTHER NON-FERROUS ALLOYS (INCLUDING Cu-Fe)

J. L. HAUGHTON

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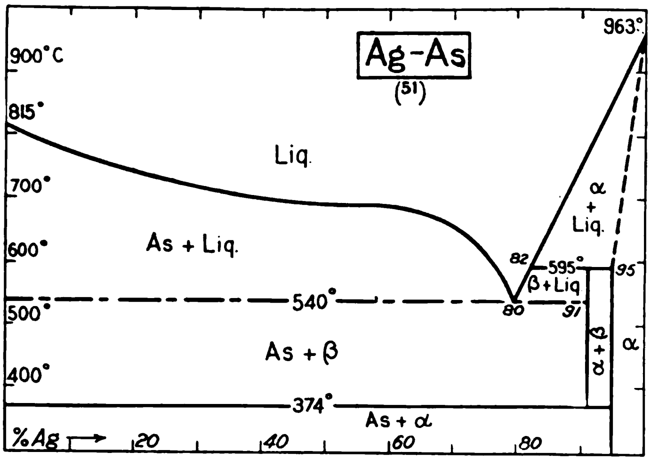
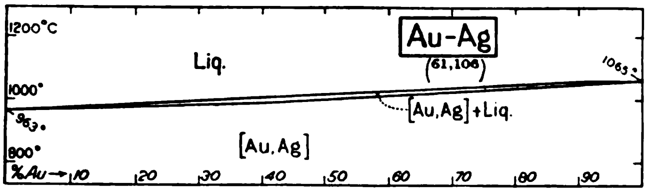
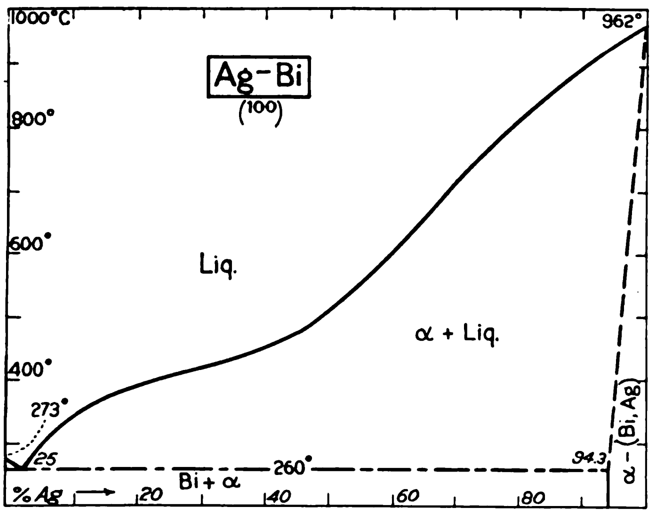
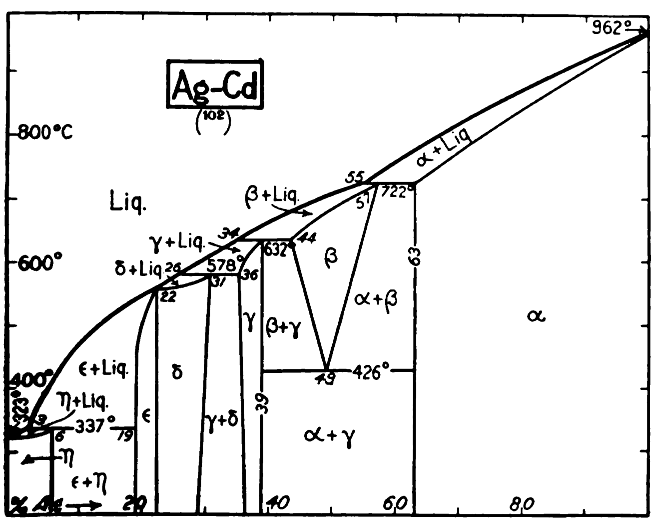
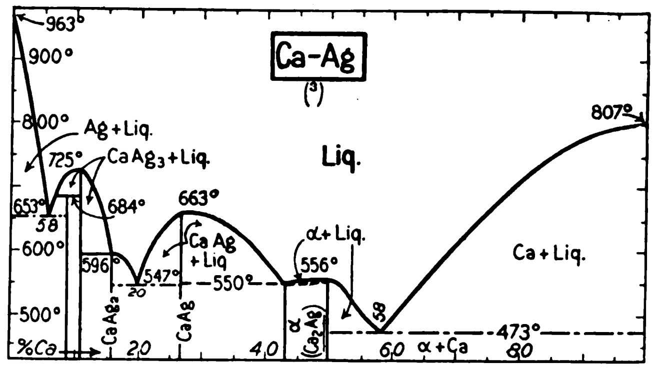
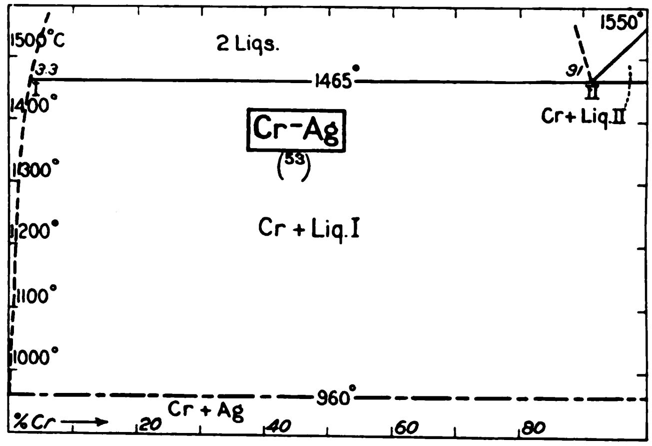

Ag-As
(51)
900°C
815°
700°
600°
500°
400°
963°
Liq.
As + Liq.
α + Liq.
82
595°
β+Liq
95
540°
80
91
As + β
α + β
α
374°
As + α
%Ag → 20 40 60 80

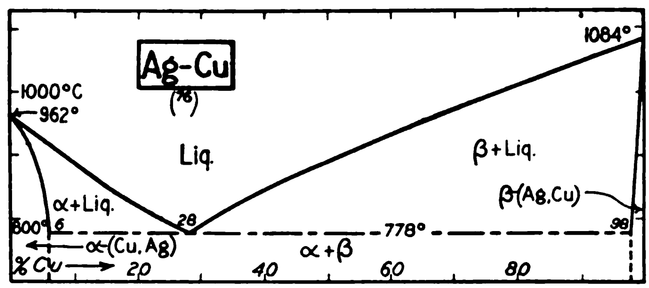

Au-Ag
(61,106)
1200°C
1000°
800°
963°
1063°
Liq.
[Au,Ag]+Liq.
[Au,Ag]
%Au → 10 20 30 40 50 60 70 80 90

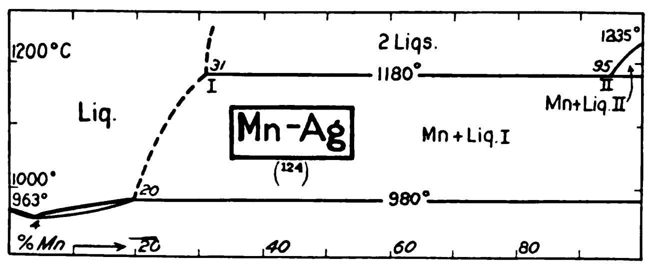

Ag-Bi
(100)
1000°C
800°
600°
400°
962°
Liq.
α + Liq.
273°
25
94.3
260°
Bi + α
α - (Bi, Ag)
%Ag → 20 40 60 80

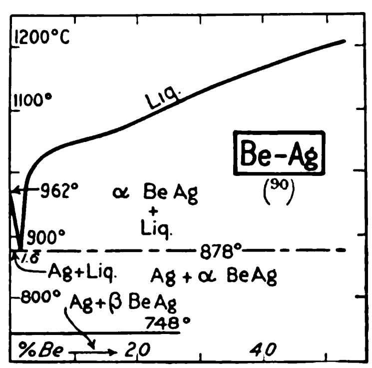

Ag-Cd
(102)
962°
800°C
600°
400°
Liq.
α+Liq
β+Liq.
55
722°
51
63
γ+Liq.
34
632°
44
β
δ+Liq
24
578°
31
36
22
α+β
γ
β+γ
α
ε+Liq.
δ
426°
49
η+Liq.
337°
79
ε
γ+δ
39
α+γ
η
ε+η
%Ag → 20 40 60 80

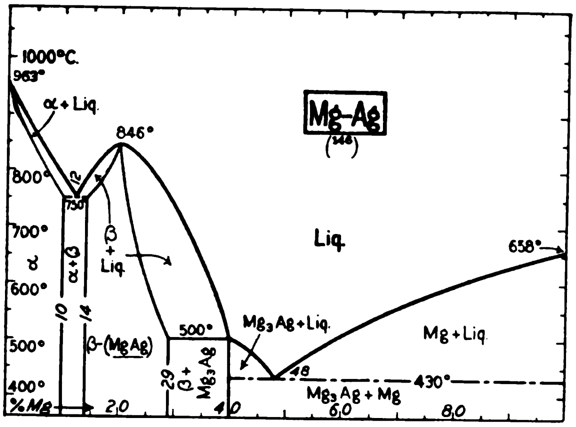

Ca-Ag
(3)
963°
900°
800°
Ag+Liq.
725°
CaAg3+Liq.
Liq.
807°
684°
663°
653°
58
600°
596°
CaAg + Liq
547°
α+Liq.
556°
Ca+Liq.
20
550°
500°
58
CaAg2
CaAg
α
(Ca2Ag)
473°
α+Ca
%Ca → 20 40 60 80

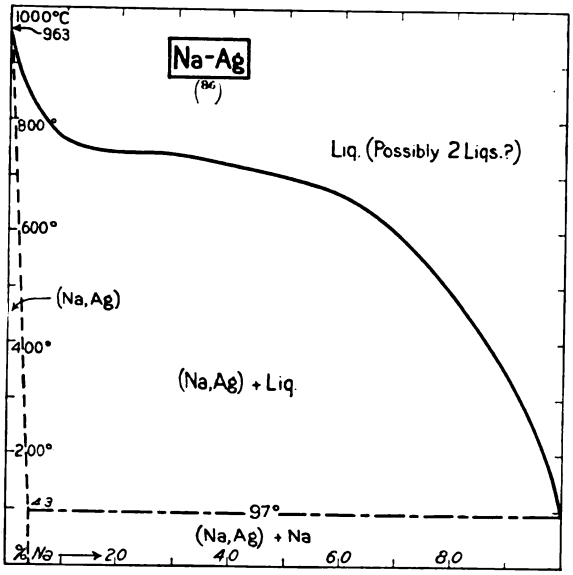

Cr-Ag
(53)
1500°C
2 Liqs.
1550°
3.3
1465°
91
I
II
1400°
Cr+Liq.II
1300°
Cr + Liq. I
1200°
1100°
1000°
960°
Cr + Ag
%Cr → 20 40 60 80

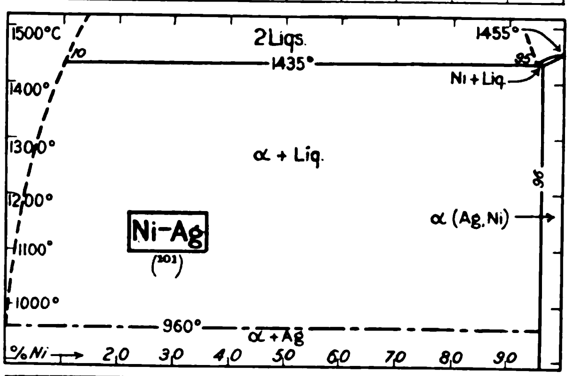

Ag-Cu
(76)
1084°
1000°C
962°
Liq.
β+Liq.
α+Liq.
β(Ag,Cu)
800°
6
28
778°
98
α(Cu,Ag)
α+β
%Cu → 20 40 60 80

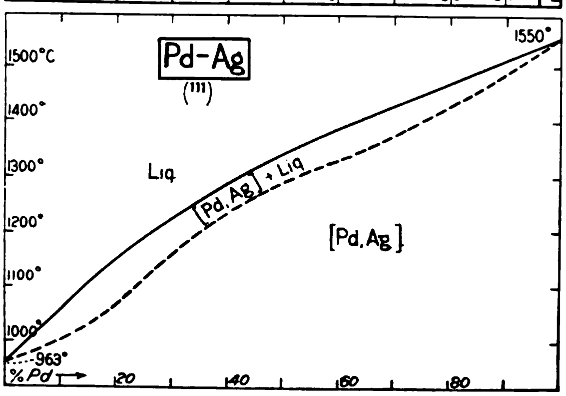

Mn-Ag
(124)
1200°C
2 Liqs.
1235°
31
1180°
95
I
II
Liq.
Mn + Liq. I
Mn+Liq.II
1000°
963°
20
980°
4
%Mn → 20 40 60 80

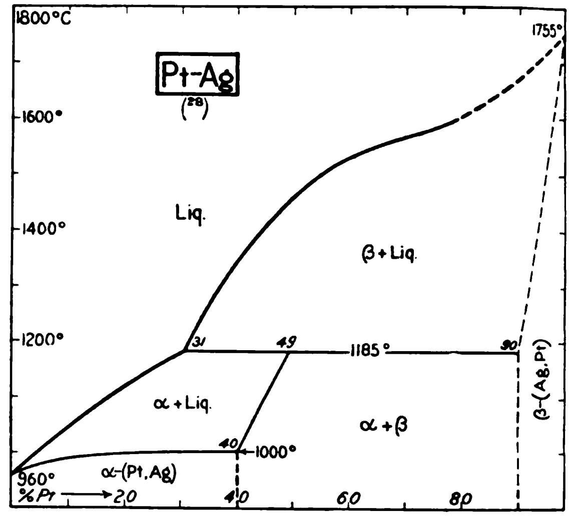

Be-Ag
(90)
1200°C
1100°
Liq.
962°
α BeAg + Liq.
900°
1.8
878°
Ag+Liq.
Ag + α BeAg
800°
Ag+β BeAg
748°
%Be → 20 40

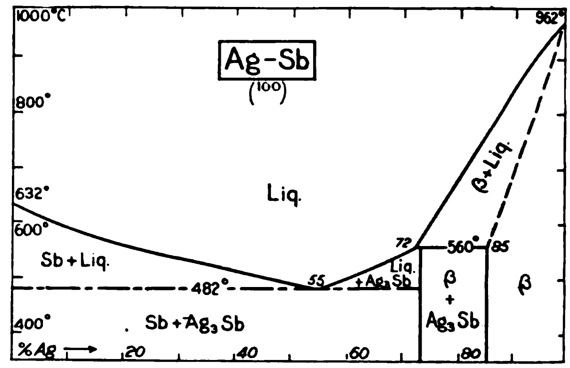

Mg-Ag
(148)
1000°C.
963°
α + Liq.
846°
800°
750
12
700°
β + Liq.
Liq.
658°
600°
α
α+β
10
14
500°
β-(MgAg)
500°
Mg3Ag+Liq.
Mg+Liq.
29
β + Mg3Ag
48
430°
400°
Mg3Ag + Mg
%Mg 20 40 60 80

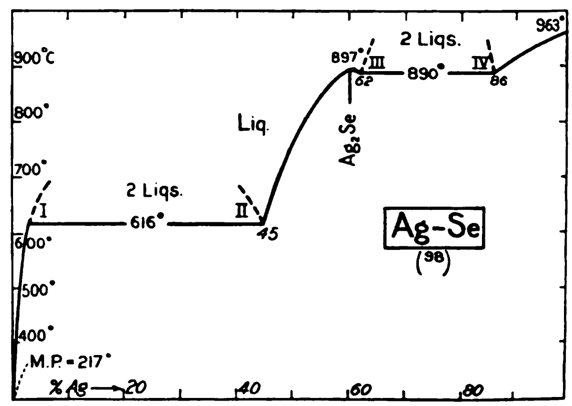

1000°C
963
Na-Ag
(86)
800°
Liq. (Possibly 2 Liqs.?)
600°
(Na,Ag)
400°
(Na,Ag) + Liq.
200°
43
97°
(Na,Ag) + Na
%Na 20 40 60 80

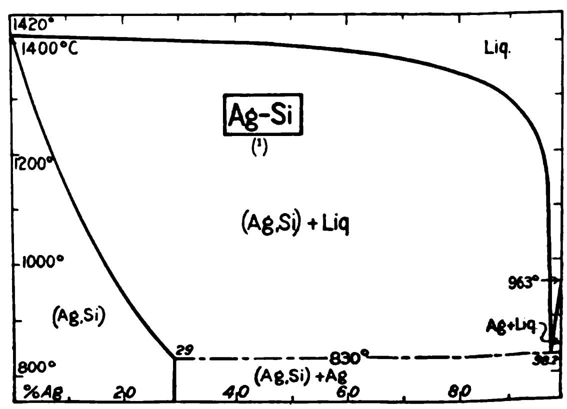

1500°C
2 Liqs.
1455°
10
1435°
85
Ni + Liq.
1400°
1300°
α + Liq.
1200°
96
α (Ag,Ni)
Ni-Ag
(301)
1100°
1000°
960°
α + Ag
%Ni 20 30 40 50 60 70 80 90

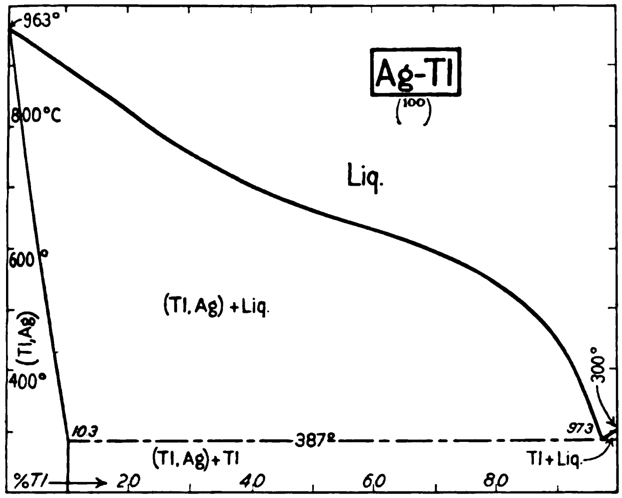

1550°
1500°C
Pd-Ag
(111)
1400°
1300°
Liq.
[Pd,Ag] + Liq.
1200°
[Pd,Ag]
1100°
1000°
963°
%Pd 20 40 60 80

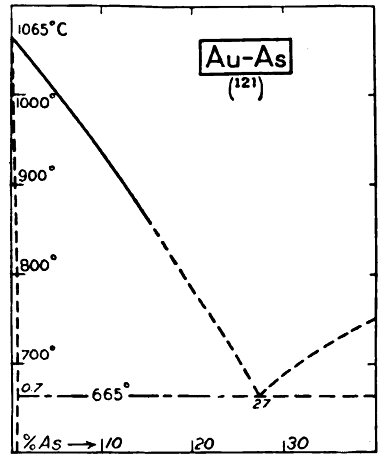

1800°C
1755°
Pt-Ag
(28)
1600°
Liq.
1400°
β + Liq.
1200°
31
49
1185°
90
β-(Ag,Pt)
α + Liq.
α + β
40
1000°
960°
α-(Pt,Ag)
%Pt 20 40 60 80

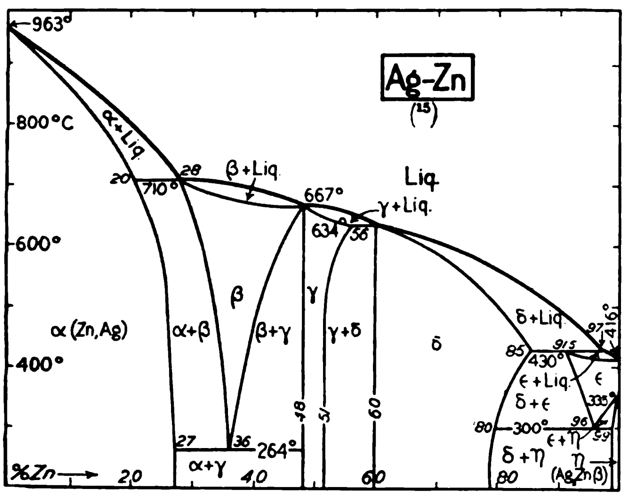

1000°C
962°
Ag-Sb
(100)
800°
β+Liq.
632°
Liq.
600°
Sb + Liq.
72
560°
85
55
482°
Liq. + Ag3Sb
β + Ag3Sb
β
400°
Sb + Ag3Sb
%Ag 20 40 60 80

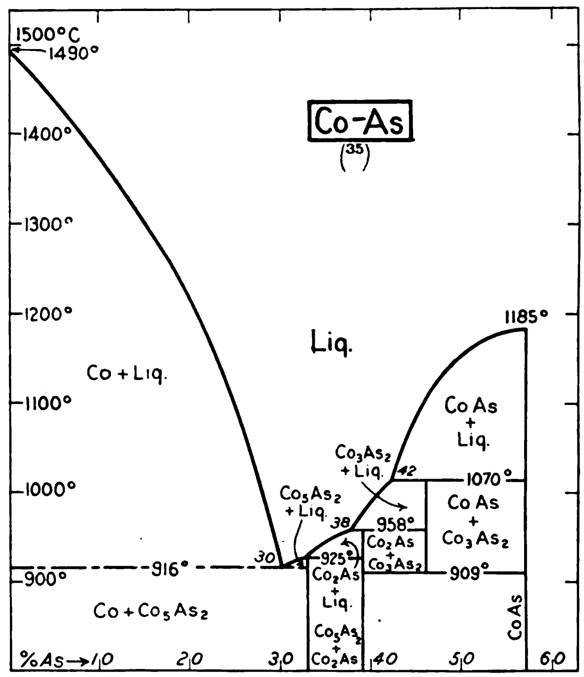

963°
2 Liqs.
900°C
897°
III
890°
IV
62
86
800°
Liq.
Ag2Se
700°
2 Liqs.
I
616°
II
600°
45
Ag-Se
(98)
500°
400°
M.P. = 217°
%Ag 20 40 60 80

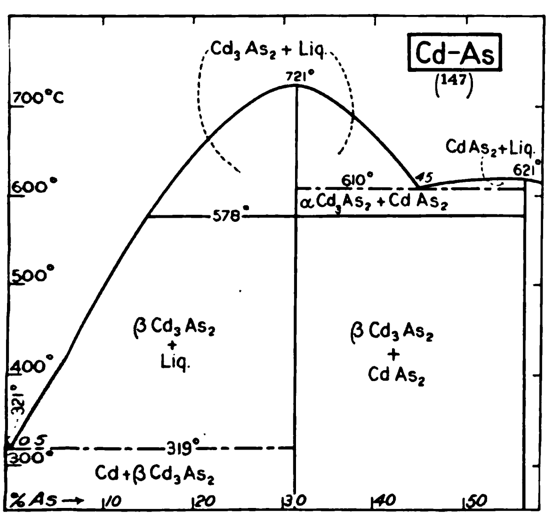

1420°
1400°C
Liq.
Ag-Si
(1)
1200°
(Ag,Si) + Liq
1000°
963°
(Ag,Si)
Ag+Liq.
29
830°
800°
(Ag,Si) + Ag
%Ag 20 40 60 80

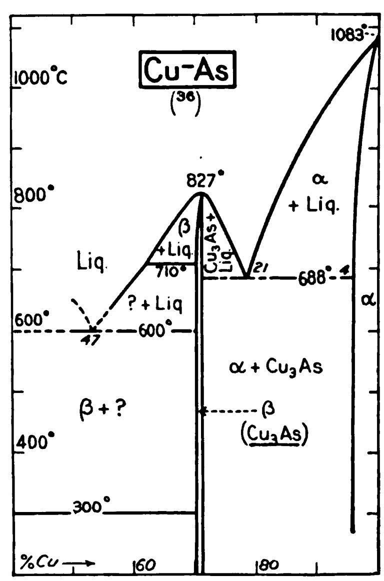

Ag-Tl
(100)
963°
800°C
600°
400°
(Tl, Ag)
Liq.
(Tl, Ag) + Liq.
300°
103
387°
973
(Tl, Ag) + Tl
Tl + Liq.
%Tl
20
40
60
80

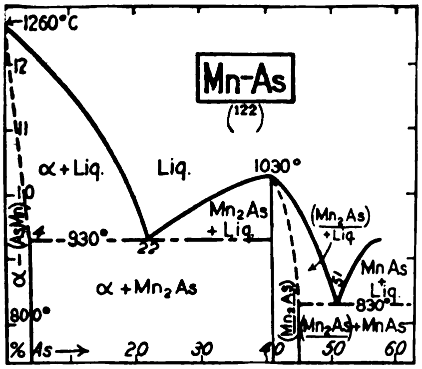

Au-As
(121)
1065°C
1000°
900°
800°
700°
0.7
665°
27
%As
10
20
30

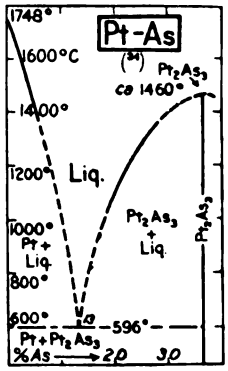

Ag-Zn
(15)
963°
800°C
600°
400°
α + Liq.
β + Liq.
Liq.
20
28
710°
667°
γ + Liq.
634°
56
β
γ
α (Zn, Ag)
α + β
β + γ
γ + δ
δ
δ + Liq.
416°
97
85
915
430°
ε + Liq.
δ + ε
ε
335°
80
300°
96
ε + η
59
δ + η
η
(AgZn β)
27
36
264°
α + γ
48
51
60
%Zn
20
40
60
80

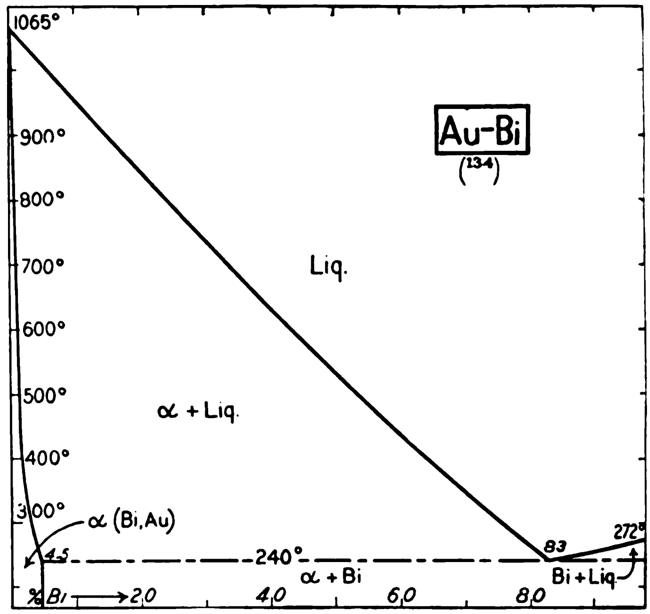

Co-As
(35)
1500°C
1490°
1400°
1300°
1200°
1100°
1000°
900°
1185°
Liq.
Co + Liq.
Co As + Liq.
Co₃As₂ + Liq.
42
1070°
Co₅As₂ + Liq.
38
958°
Co As + Co₃As₂
Co₂As + Co₃As₂
30
916°
925°
909°
Co₂As + Liq.
Co₅As₂ + Co₂As
Co + Co₅As₂
Co As
%As
10
20
30
40
50
60

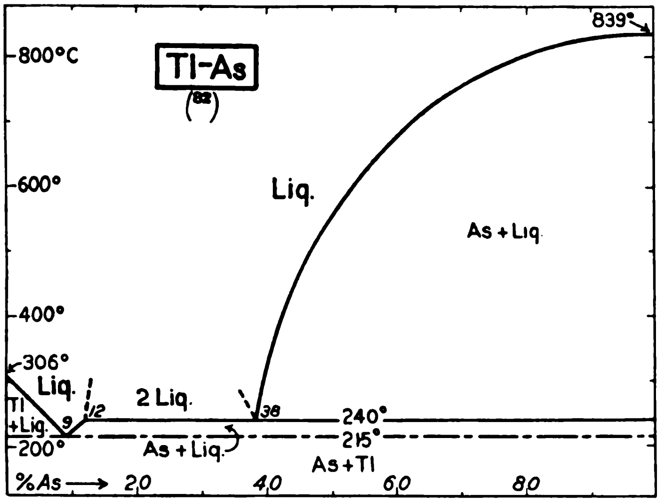

Cd-As
(147)
Cd₃ As₂ + Liq.
721°
700°C
600°
500°
400°
321°
300°
Cd As₂ + Liq.
610°
45
621°
578°
α Cd₃ As₂ + Cd As₂
β Cd₃ As₂ + Liq.
β Cd₃ As₂ + Cd As₂
0.5
319°
Cd + β Cd₃ As₂
%As
10
20
30
40
50

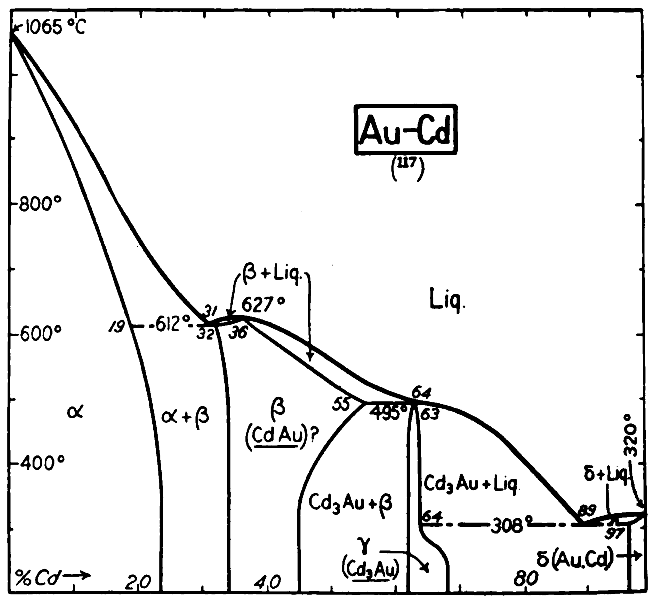

Cu-As
(36)
1083°
1000°C
800°
600°
400°
827°
β + Liq.
Cu₃As + Liq.
710°
α + Liq.
21
688°
4
Liq.
? + Liq.
47
600°
α
α + Cu₃As
β + ?
β (Cu₃As)
300°
%Cu
60
80

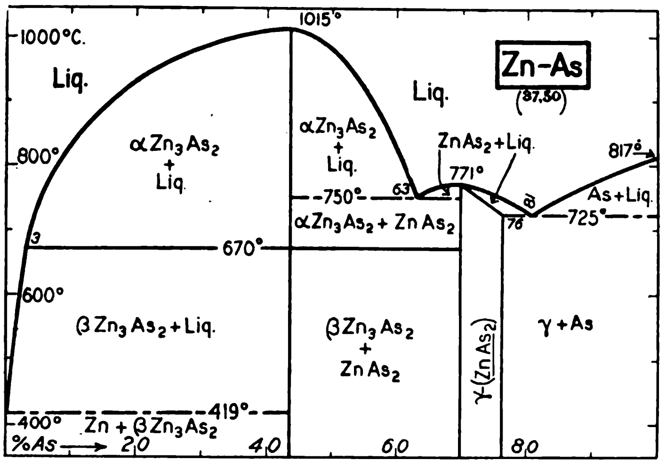

Mn-As
(122)
1260°C
Liq.
α + Liq.
1030°
Mn2As + Liq.
(Mn2As) + Liq.
930°
22
α + Mn2As
MnAs + Liq.
830°
Mn2As + MnAs
800°
%As
20
30
40
50
60

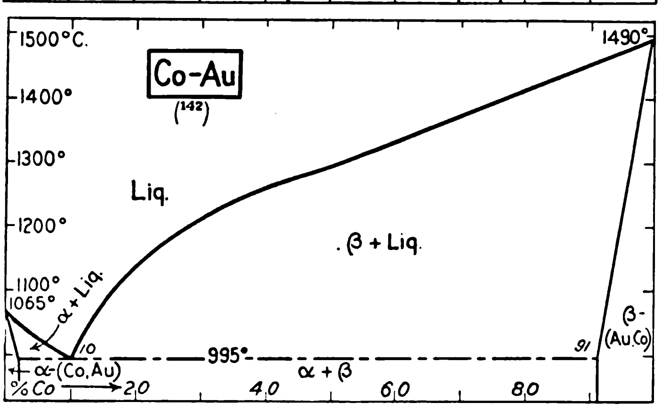

Pt-As
(34)
1748°
1600°C
Pt2As3
ca 1460°
1400°
1200°
Liq.
Pt2As3 + Liq.
1000°
Pt + Liq.
800°
600°
596°
Pt + Pt2As3
%As
20
30

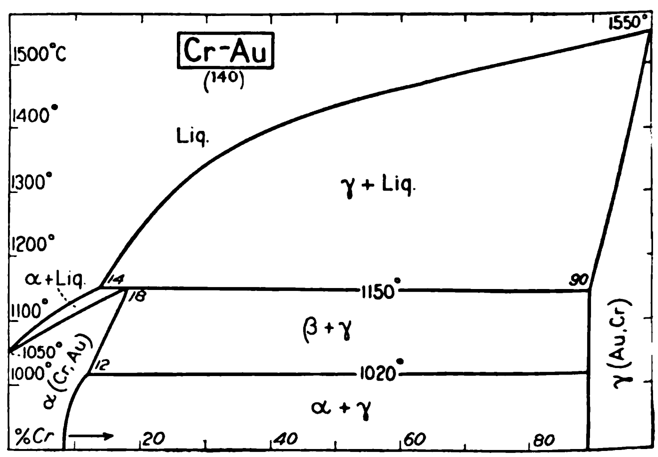

Au-Bi
(134)
1065°
900°
800°
700°
600°
500°
400°
300°
Liq.
α + Liq.
α (Bi, Au)
4.5
240°
83
272°
α + Bi
Bi + Liq.
%Bi
20
40
60
80

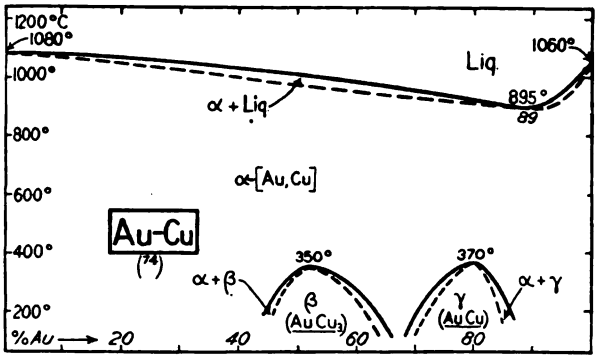

Tl-As
(82)
839°
800°C
600°
400°
306°
200°
Liq.
As + Liq.
Tl + Liq.
2 Liq.
9
12
38
240°
215°
As + Liq.
As + Tl
%As
20
40
60
80

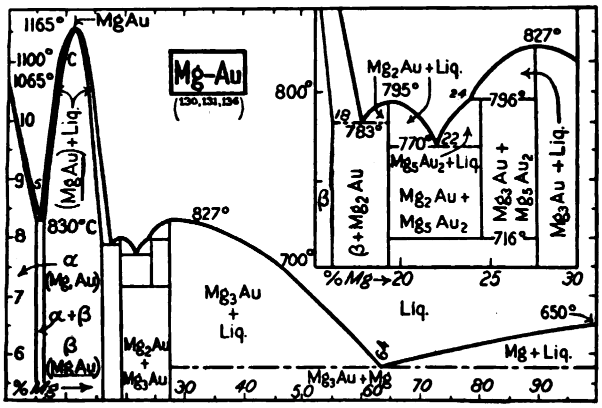

Au-Cd
(117)
1065 °C
800°
600°
400°
Liq.
β + Liq.
627°
612°
19
31
32
36
α
α + β
β (CdAu)?
55
64
495°
63
Cd3Au + β
Cd3Au + Liq.
γ (Cd3Au)
64
308°
89
97
δ + Liq.
320°
δ (Au, Cd)
%Cd
20
40
80

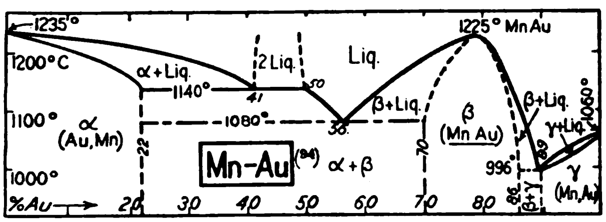

Zn-As
(87,50)
1015°
1000°C.
Liq.
Liq.
800°
αZn3As2 + Liq.
αZn3As2 + Liq.
ZnAs2 + Liq.
817°
771°
750°
63
81
76
725°
As + Liq.
αZn3As2 + ZnAs2
3
670°
600°
βZn3As2 + Liq.
βZn3As2 + ZnAs2
γ (ZnAs2)
γ + As
400°
419°
Zn + βZn3As2
%As
20
40
60
80

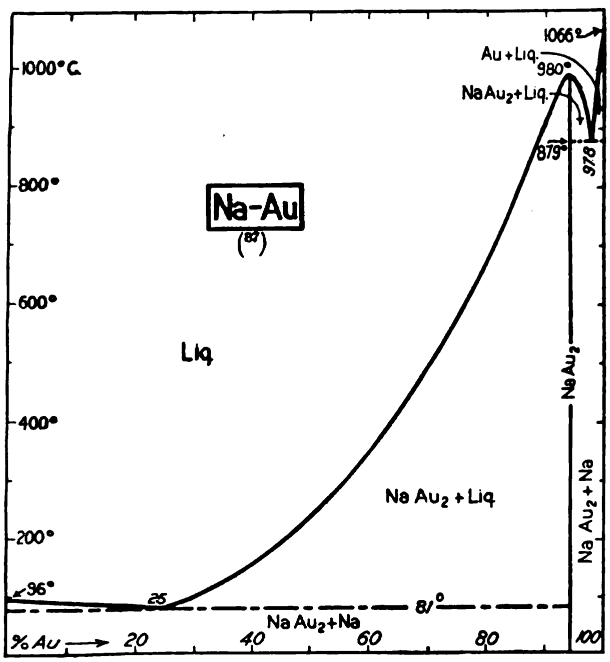

Co-Au
(142)
1500°C.
1490°
1400°
1300°
1200°
1100°
1065°
Liq.
β + Liq.
α + Liq.
10
995°
91
β (Au, Co)
α (Co, Au)
α + β
%Co
20
40
60
80

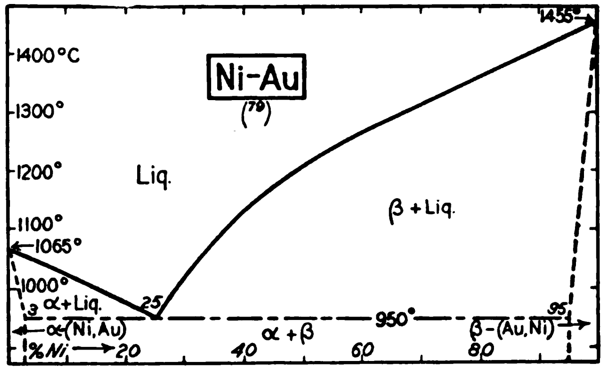

Cr-Au
(140)
1550°
1500°C
1400°
1300°
1200°
1100°
1050°
1000°
Liq.
γ + Liq.
α + Liq.
14
18
1150°
90
β + γ
12
1020°
α + γ
α (Cr, Au)
γ (Au, Cr)
%Cr
20
40
60
80

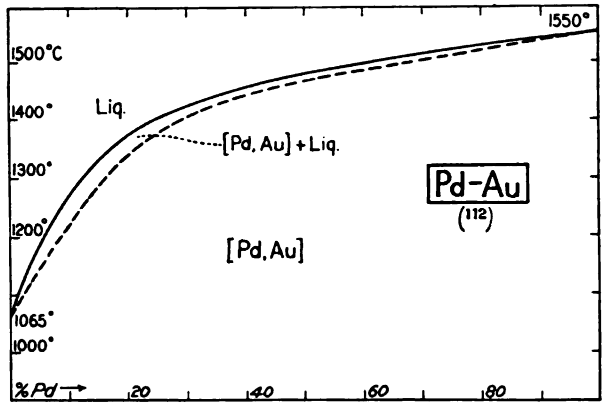

Au-Cu
(74)
1200°C
1080°
1060°
1000°
800°
600°
400°
200°
Liq.
α + Liq.
895°
89
α-[Au,Cu]
350°
370°
α+β
α+γ
β
(AuCu3)
γ
(AuCu)
%Au → 20 40 60 80

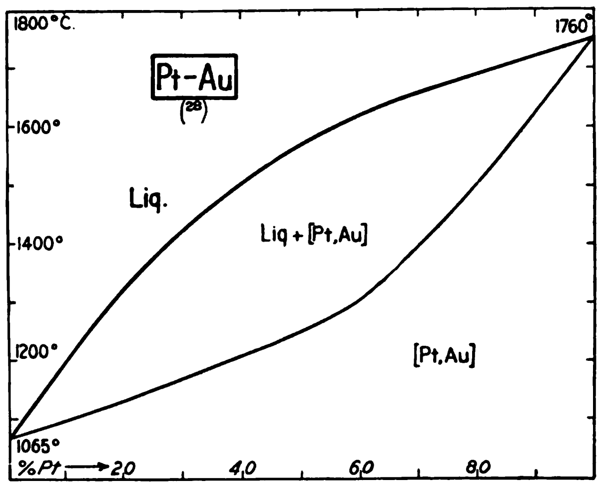

Mg-Au
(130,131,134)
1165°
MgAu
1100°
1065°
830°C
α
(Mg,Au)
α+β
β
(MgAu)
(MgAu) + Liq.
Mg2Au + Mg3Au
Mg3Au + Liq.
827°
700°
Liq.
650°
Mg + Liq.
Mg3Au + Mg
64
%Mg → 30 40 50 60 70 80 90
800°
Mg2Au + Liq.
795°
783°
18
770°
22
24
796°
827°
Mg5Au2 + Liq.
Mg2Au + Mg5Au2
Mg3Au + Mg5Au2
Mg3Au + Liq.
β + Mg2Au
716°
%Mg → 20 25 30

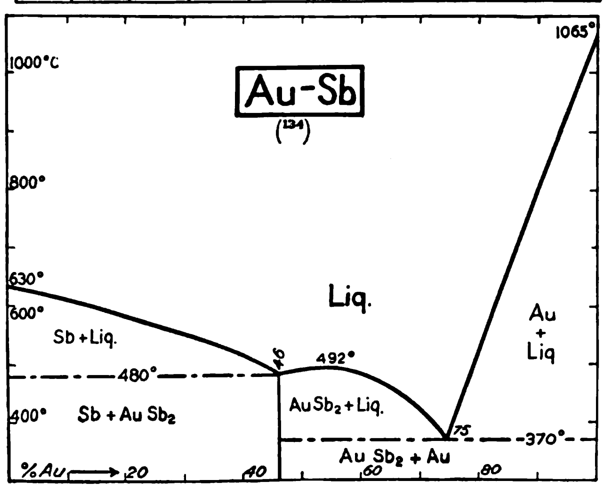

1235°
1225° MnAu
1200°C
α + Liq.
1140°
41
2 Liq.
50
Liq.
1080°
38
β+Liq.
β
(MnAu)
β+Liq.
γ+Liq.
1060°
1100°
α
(Au,Mn)
Mn-Au
(94)
α+β
996°
γ
(Mn,Au)
β+γ
1000°
%Au → 20 30 40 50 60 70 80

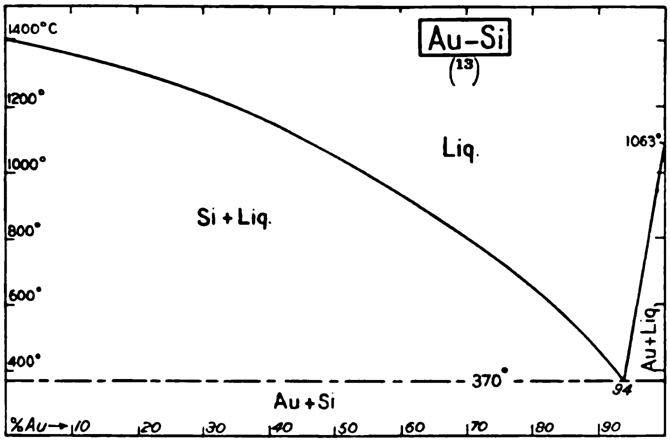

1066°
Au+Liq.
980°
NaAu2+Liq.
1000°C
879°
978
800°
Na-Au
(87)
600°
Liq.
400°
NaAu2
Na Au2 + Liq.
Na Au2 + Na
200°
96°
25
81°
Na Au2+Na
%Au → 20 40 60 80 100

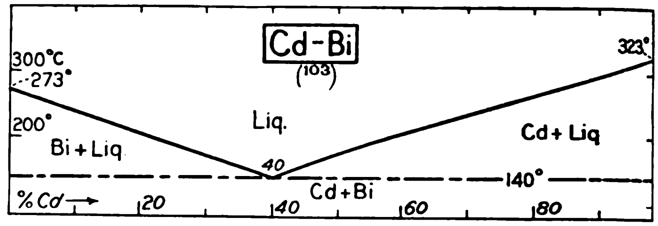

1455°
1400°C
Ni-Au
(79)
1300°
1200°
Liq.
β + Liq.
1100°
1065°
1000°
α+Liq.
25
950°
95
α-(Ni,Au)
α + β
β-(Au,Ni)
%Ni → 20 40 60 80

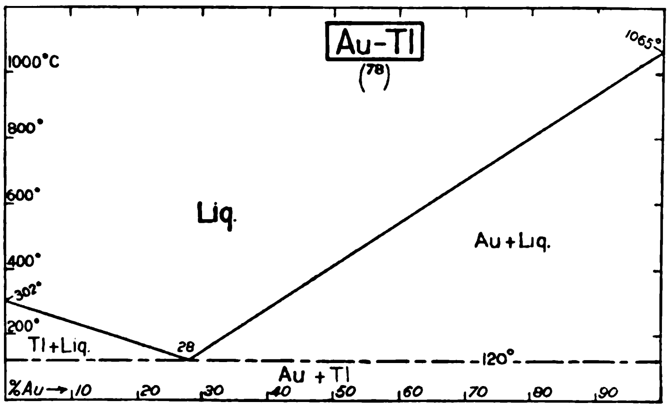

1550°
1500°C
1400°
Liq.
[Pd, Au] + Liq.
1300°
Pd-Au
(112)
1200°
[Pd, Au]
1065°
1000°
%Pd → 20 40 60 80

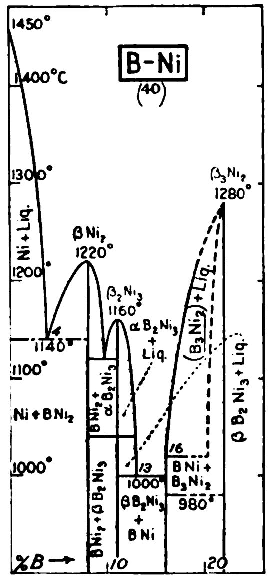

1800°C.
1760°
Pt-Au
(28)
1600°
Liq.
Liq + [Pt, Au]
1400°
1200°
[Pt, Au]
1065°
%Pt → 20 40 60 80

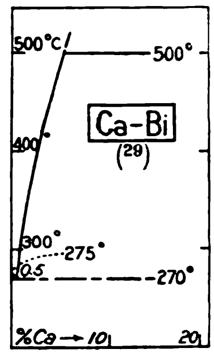

1065°
1000°C
Au-Sb
(134)
800°
630°
600°
Liq.
Au + Liq
Sb + Liq.
480°
46
492°
AuSb2 + Liq.
400°
Sb + Au Sb2
75
370°
Au Sb2 + Au
%Au → 20 40 60 80

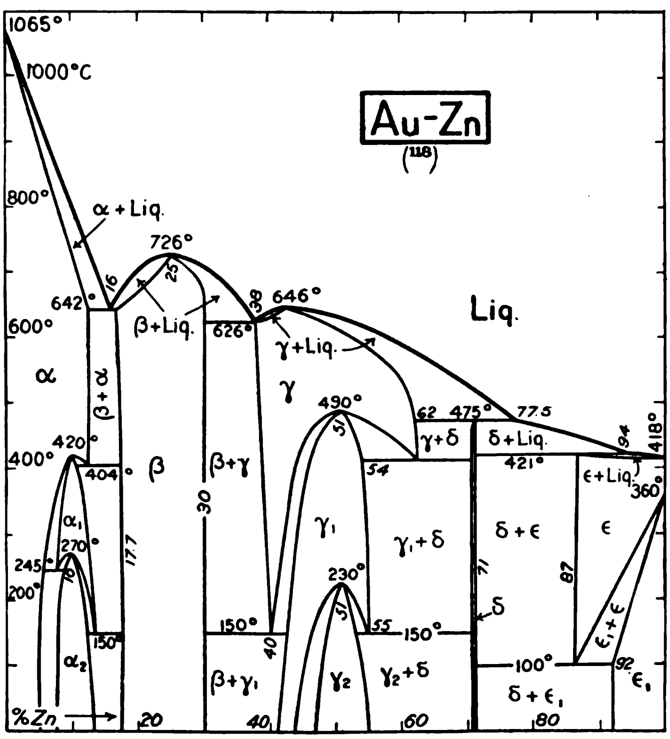

Au-Si
(13)
1400°C
1200°
1000°
800°
600°
400°
Liq.
Si + Liq.
1063°
Au+Liq.
370°
94
Au+Si
%Au→ 10 20 30 40 50 60 70 80 90

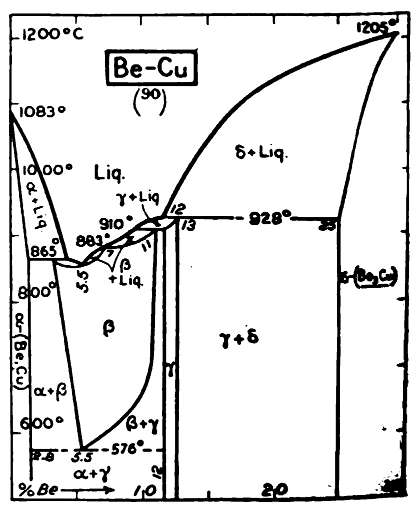

Cd-Bi
(103)
300°C
273°
323°
200°
Bi + Liq
Liq.
Cd + Liq
40
140°
Cd+Bi
%Cd→ 20 40 60 80

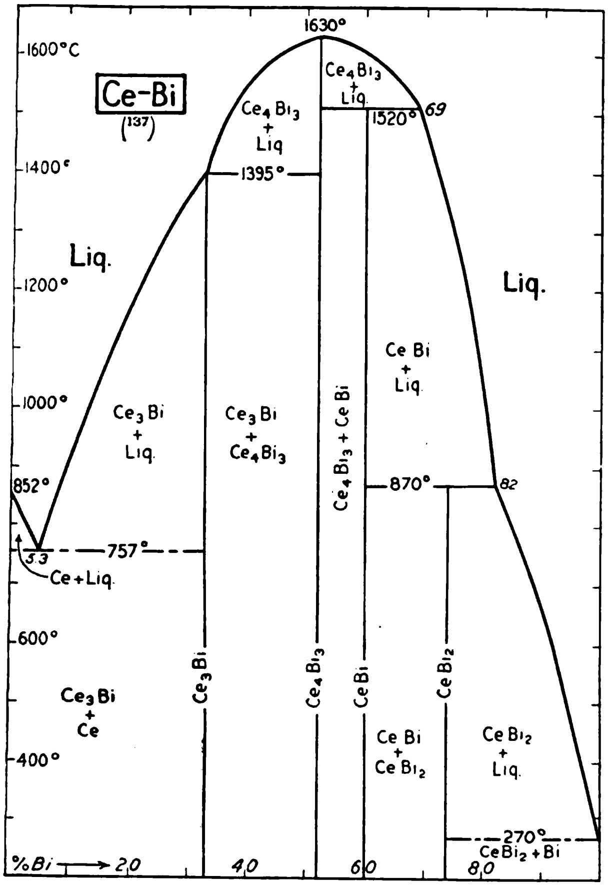

Au-Tl
(78)
1000°C
1065°
800°
600°
400°
302°
200°
Liq.
Au + Liq.
Tl+Liq.
28
120°
Au + Tl
%Au→ 10 20 30 40 50 60 70 80 90

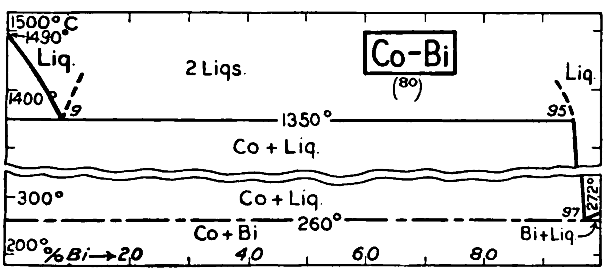

B-Ni
(40)
1450°
1400°C
1300°
1200°
1100°
1000°
Ni+Liq.
βNi₂
1220°
β₂Ni₃
1160°
β₃Ni₂
1280°
αB₂Ni₃ + Liq.
1140°
Ni+BNi₂
(B₃Ni₂)+Liq.
β B₂Ni₃ + Liq.
16
13
1000°
980°
BNi + B₃Ni₂
βB₂Ni₃ + BNi
%B→ 10 20

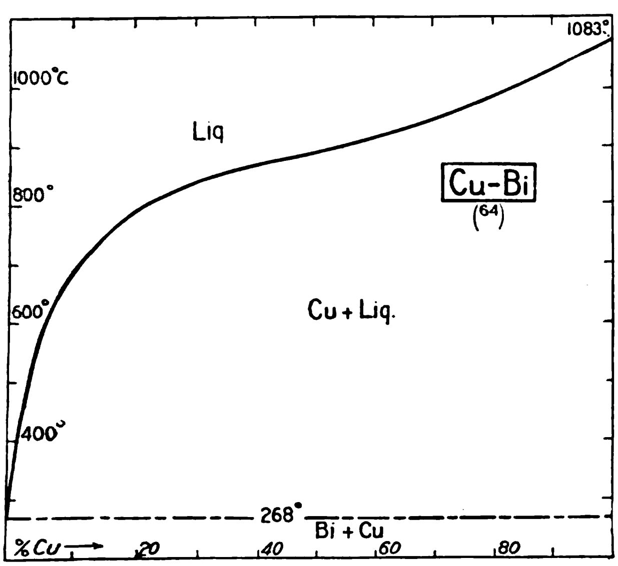

Ca-Bi
(29)
500°C
500°
400°
300°
275°
270°
0.5
%Ca→ 10 20

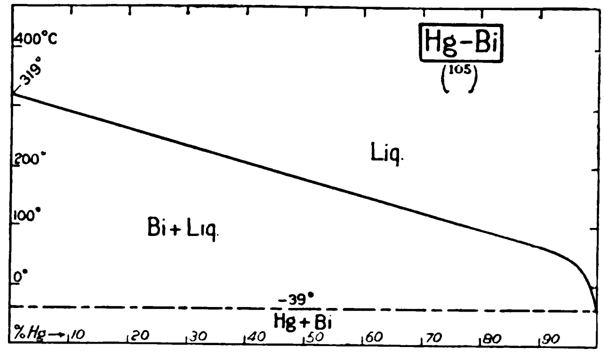

Au-Zn
(118)
1065°
1000°C
800°
600°
400°
200°
α + Liq.
726°
642°
16
25
β+Liq.
626°
38
646°
γ+Liq.
Liq.
α
β+α
γ
490°
62
475°
77.5
δ+Liq.
94
418°
420°
404°
β
β+γ
421°
ε+Liq.
360°
α₁
270°
245°
γ₁
γ₁+δ
δ+ε
ε
17.7
30
54
71
87
150°
150°
40
230°
55
150°
δ
ε₁+ε
α₂
β+γ₁
γ₂
γ₂+δ
100°
δ+ε₁
ε₁
%Zn → 20 40 60 80

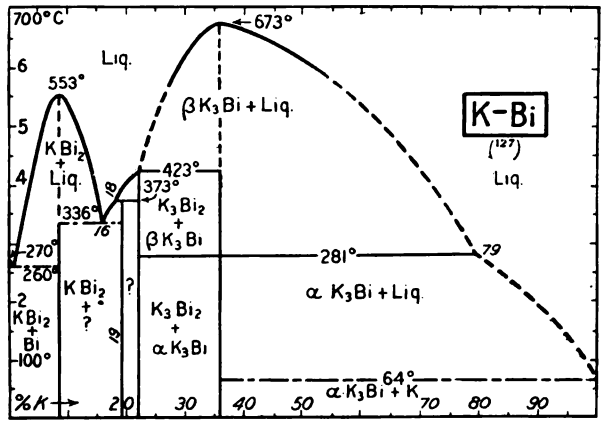

Be-Cu
(90)
1200°C
1205°
1083°
1000°
Liq.
δ+Liq.
γ+Liq.
910°
883°
865°
12
13
928°
35
β + Liq.
800°
β
γ+δ
δ(Be₂Cu)
α(Be,Cu)
α+β
600°
β+γ
γ
2.8
3.5
576°
α+γ
%Be → 10 20

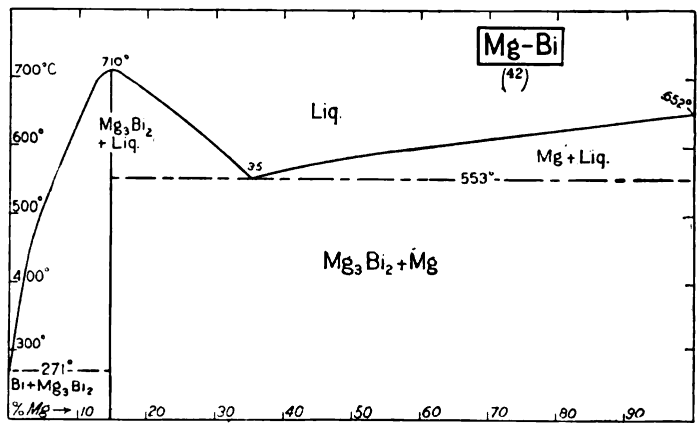

Ce-Bi
(137)
1630°
1600°C
1400°
1200°
1000°
600°
400°
Ce4 Bi3 + Liq
1520°
69
1395°
Liq.
Liq.
Ce Bi + Liq.
Ce3 Bi + Liq.
Ce3 Bi + Ce4 Bi3
Ce4 Bi3 + Ce Bi
870°
82
852°
757°
5.3
Ce + Liq.
Ce3 Bi + Ce
Ce3 Bi
Ce4 Bi3
Ce Bi
Ce Bi2
Ce Bi + Ce Bi2
Ce Bi2 + Liq.
270°
CeBi2 + Bi
%Bi → 20
40
60
80

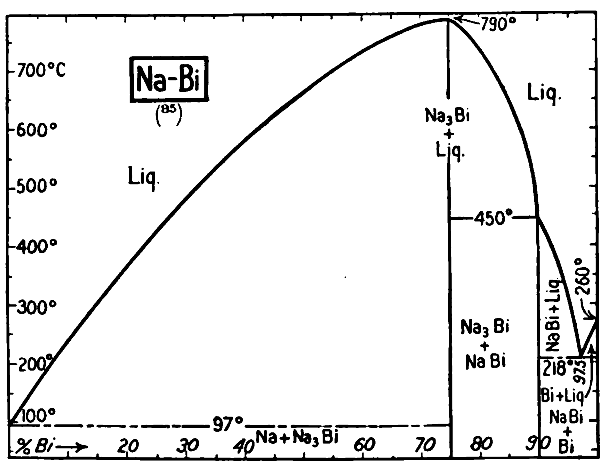

Co-Bi
(80)
1500°C
1490°
Liq.
2 Liqs.
Liq.
1400
19
95
1350°
Co + Liq.
300°
Co + Liq.
272°
260°
97
Co + Bi
Bi+Liq.
200° %Bi → 20
40
60
80

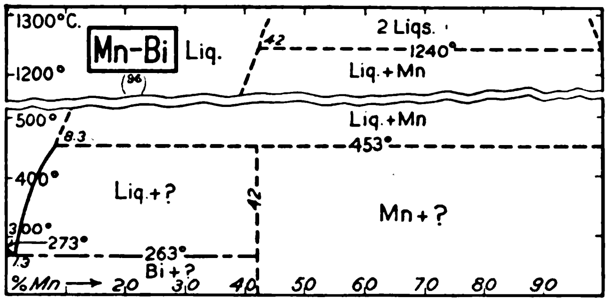

1083°
1000°C
Liq
Cu-Bi
(64)
800°
600°
Cu + Liq.
400°
268°
Bi + Cu
%Cu → 20
40
60
80


Hg-Bi
(105)
400°C
319°
200°
Liq.
100°
Bi + Liq.
0°
-39°
Hg + Bi
%Hg → 10
20
30
40
50
60
70
80
90

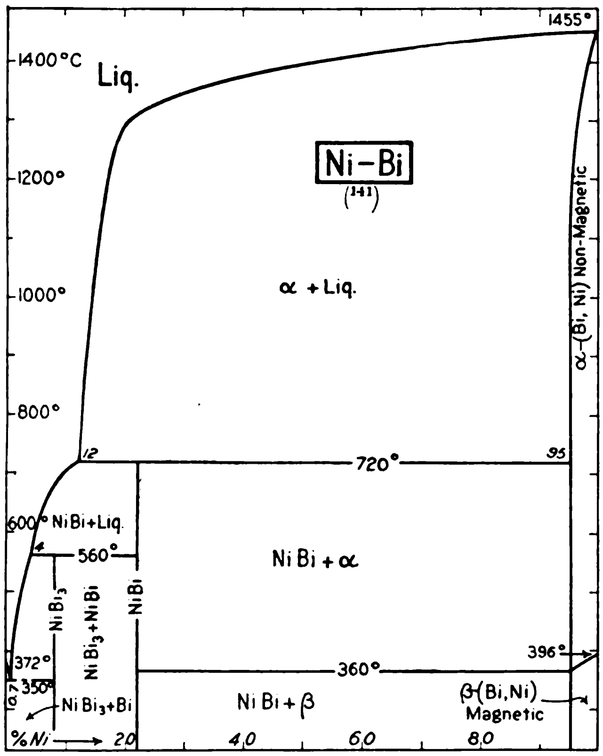

700°C
673°
Liq.
553°
β K3Bi + Liq.
K-Bi
(127)
Liq.
K Bi2 + Liq.
423°
373°
336°
18
16
K3 Bi2 + β K3 Bi
270°
260°
281°
79
α K3Bi + Liq.
K Bi2 + ?
?
19
K Bi2 + Bi
K3 Bi2 + α K3 Bi
64°
α K3Bi + K
%K → 20
30
40
50
70
80
90


Mg-Bi
(42)
710°
700°C
Mg3Bi2 + Liq.
Liq.
652°
600°
35
Mg + Liq.
553°
500°
Mg3 Bi2 + Mg
400°
300°
271°
Bi + Mg3 Bi2
%Mg → 10
20
30
40
50
60
70
80
90

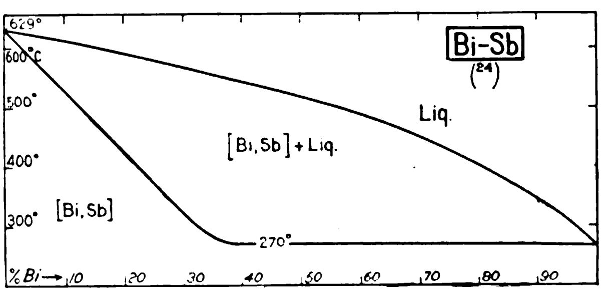

790°
700°C
Na-Bi
(85)
Liq.
600°
Na3 Bi + Liq.
500°
Liq.
450°
400°
300°
260°
NaBi + Liq.
Na3 Bi + Na Bi
200°
218°
97.3
Bi + Liq.
100°
97°
Na Bi + Bi
Na + Na3 Bi
%Bi → 20
30
40
60
70
80
90



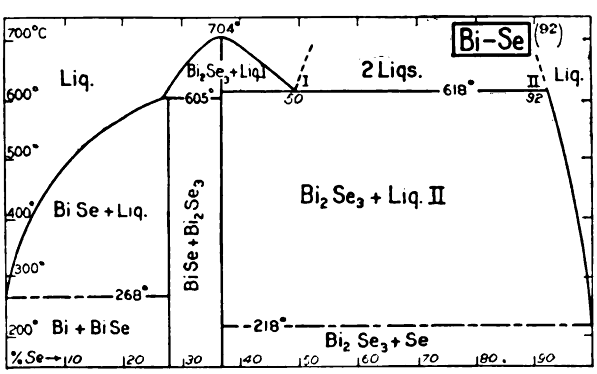
Mn-Bi
(96)
1300°C.
1200°
Liq.
2 Liqs.
1240°
Liq.+Mn
500°
453°
400°
300°
273°
263°
Liq.+?
Mn+?
Bi+?
%Mn → 20 30 40 50 60 70 80 90



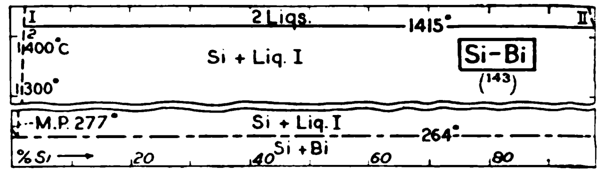
1455°
1400°C
Liq.
Ni-Bi
(141)
1200°
1000°
α + Liq.
α-(Bi, Ni) Non-Magnetic
800°
720°
600°
NiBi+Liq.
560°
NiBi₃
NiBi₃+NiBi
NiBi
NiBi + α
396°
372°
350°
360°
NiBi₃+Bi
NiBi + β
β-(Bi,Ni) Magnetic
%Ni → 20 40 60 80



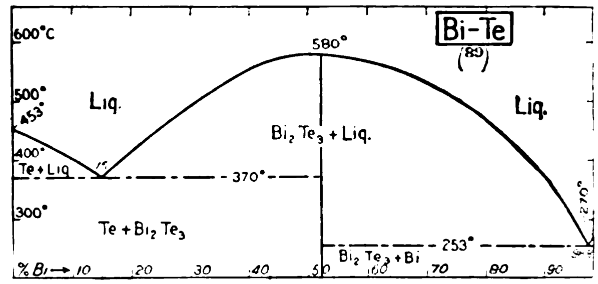
629°
600°C
500°
400°
300°
Bi-Sb
(24)
Liq.
[Bi,Sb]+Liq.
[Bi,Sb]
270°
%Bi → 10 20 30 40 50 60 70 80 90



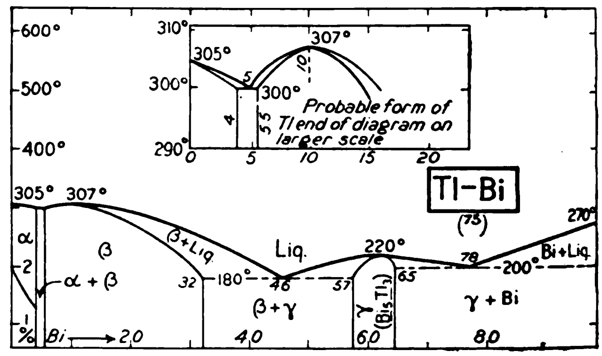
Bi-Se
(92)
700°C
704°
600°
Liq.
Bi₂Se₃+Liq.
605°
2 Liqs.
618°
Liq.
500°
400°
Bi Se + Liq.
BiSe + Bi₂Se₃
Bi₂Se₃ + Liq. II
300°
268°
200°
Bi + BiSe
218°
Bi₂ Se₃ + Se
%Se → 10 20 30 40 50 60 70 80 90



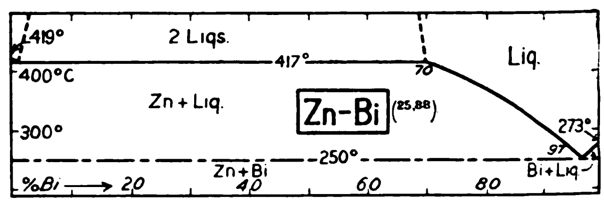
2 Liqs.
1415°
1400°C
1300°
Si + Liq. I
Si-Bi
(143)
M.P. 277°
Si + Liq. I
264°
Si + Bi
%Si → 20 40 60 80



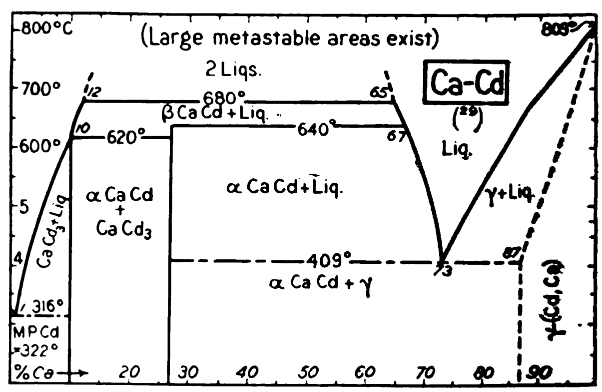
600°C
580°
Bi-Te
(89)
500°
453°
Liq.
Bi₂Te₃ + Liq.
Liq.
400°
Te+Liq.
370°
300°
Te + Bi₂Te₃
253°
Bi₂Te₃+Bi
%Bi → 10 20 30 40 50 60 70 80 90



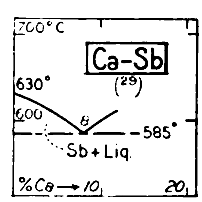
600°
500°
400°
310°
305°
307°
300°
290°
Probable form of Tl end of diagram on larger scale
0 5 10 15 20
Tl-Bi
(75)
305° 307°
270°
β
β+Liq.
Liq.
220°
Bi+Liq.
α
α + β
180°
200°
β+γ
γ
(Bi₅Tl₃)
γ + Bi
%Bi → 20 40 60 80



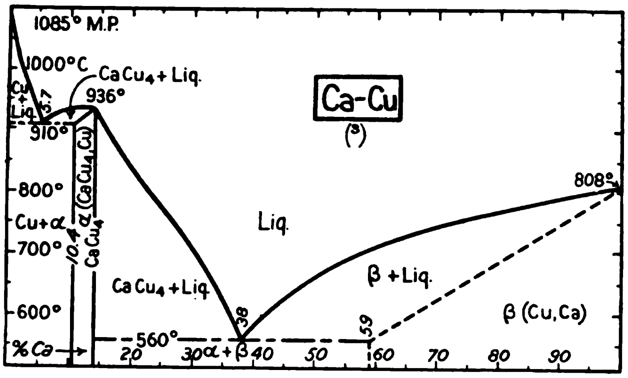
419°
2 Liqs.
417°
Liq.
400°C
Zn + Liq.
Zn-Bi
(25,88)
300°
273°
250°
Zn+Bi
Bi+Liq.
%Bi → 20 40 60 80

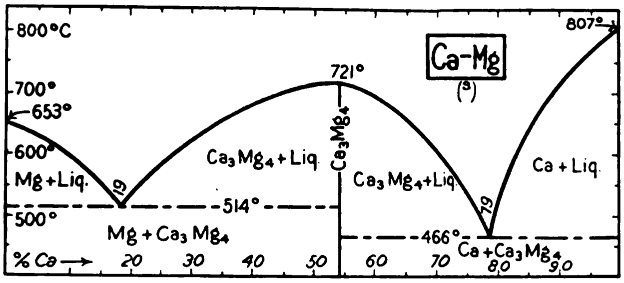


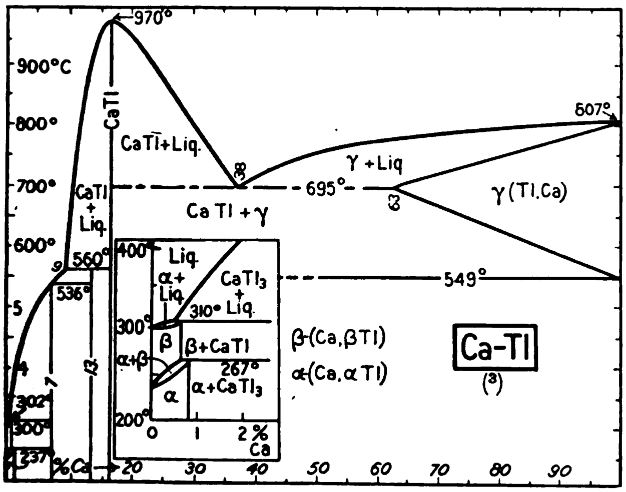
800°C
(Large metastable areas exist)
809°
2 Liqs.
700°
680°
βCaCd+Liq.
Ca-Cd
(29)
600°
620°
640°
Liq.
α CaCd + CaCd₃
α CaCd+Liq.
γ+Liq.
CaCd₃+Liq.
409°
α CaCd + γ
γ-(Cd,Ca)
316°
MP Cd
322°
%Ca → 20 30 40 50 60 70 80 90

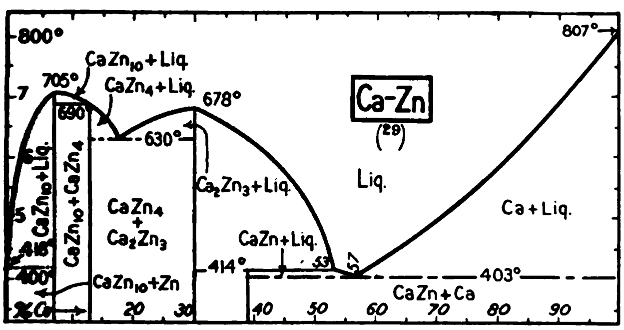


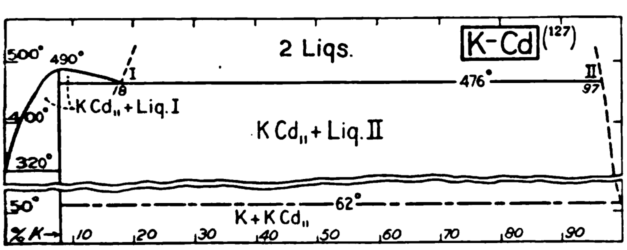
700°C
Ca-Sb
(29)
630°
600
585°
Sb+Liq.
%Ca → 10 20

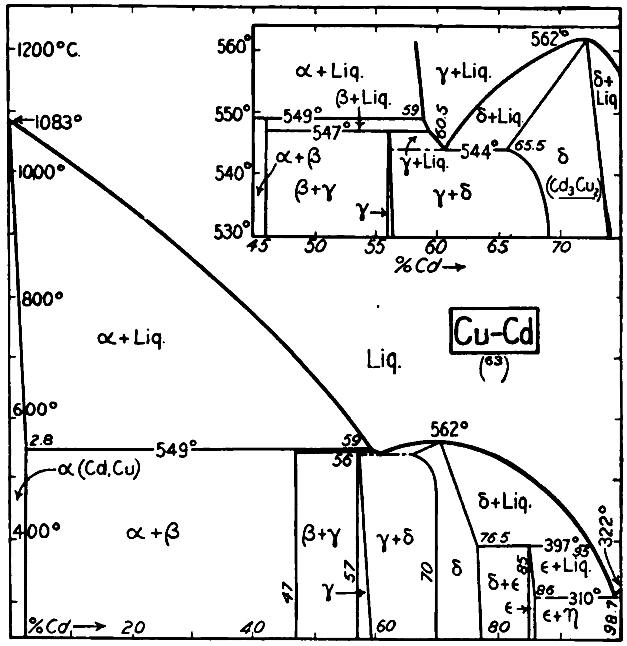

Ca-Cu
(3)
1085° M.P.
1000°C
CaCu4 + Liq.
936°
910°
808°
Liq.
CaCu4 + Liq.
β + Liq.
β (Cu,Ca)
560°
α + β
% Ca

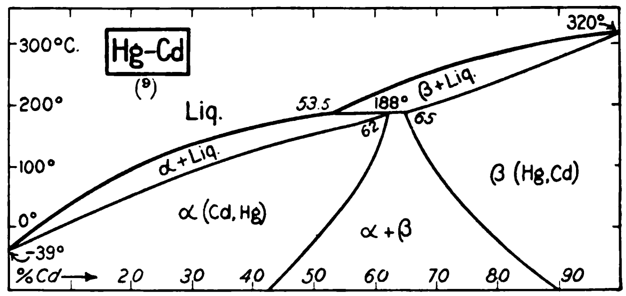

Ca-Mg
(3)
800°C
807°
721°
653°
Mg + Liq.
Ca3Mg4 + Liq.
Ca3Mg4
Ca3Mg4 + Liq.
Ca + Liq.
514°
466°
Mg + Ca3Mg4
Ca + Ca3Mg4
% Ca

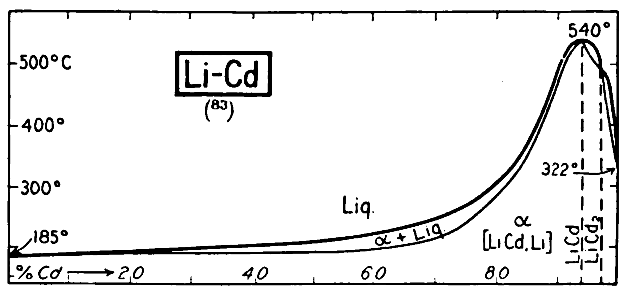

Ca-Tl
(3)
970°
900°C
CaTl
CaTl + Liq.
807°
γ + Liq
695°
γ (Tl,Ca)
CaTl + γ
549°
β-(Ca,βTl)
α-(Ca,αTl)
Liq.
CaTl3 + Liq.
310°
β + CaTl
267°
α + CaTl3
% Ca

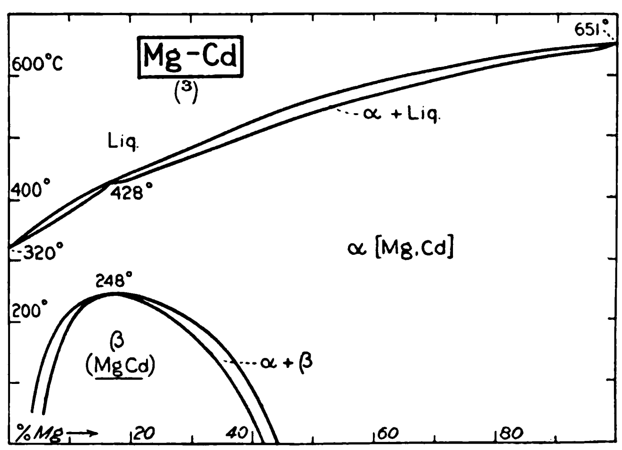

Ca-Zn
(29)
800°
807°
CaZn10 + Liq.
705°
CaZn4 + Liq.
678°
630°
Ca2Zn3 + Liq.
Liq.
Ca + Liq.
CaZn4 + Ca2Zn3
CaZn + Liq.
414°
403°
CaZn10 + Zn
CaZn + Ca
% Ca

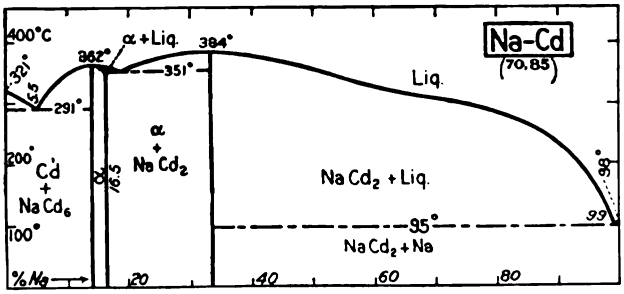

K-Cd
(127)
2 Liqs.
490°
476°
KCd11 + Liq. I
KCd11 + Liq. II
62°
K + KCd11
% K

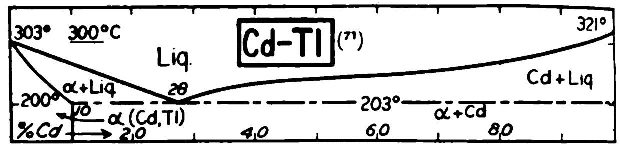

Cu-Cd
(63)
1200°C.
1083°
α + Liq.
Liq.
549°
562°
α (Cd,Cu)
α + β
β + γ
γ + δ
δ + Liq.
397°
ε + Liq.
310°
ε + η
322°
γ + Liq.
β + Liq.
δ + Liq.
544°
δ (Cd3Cu2)
% Cd

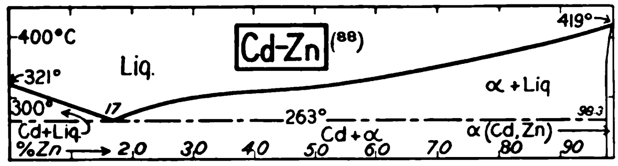

Hg-Cd
(9)
300°C.
320°
Liq.
188°
β + Liq.
α + Liq.
α (Cd, Hg)
α + β
β (Hg,Cd)
-39°
% Cd

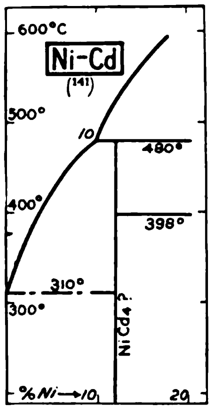

Li-Cd
(83)
540°
500°C
Liq.
322°
185°
α + Liq.
α [LiCd, Li]
LiCd
LiCd3
% Cd

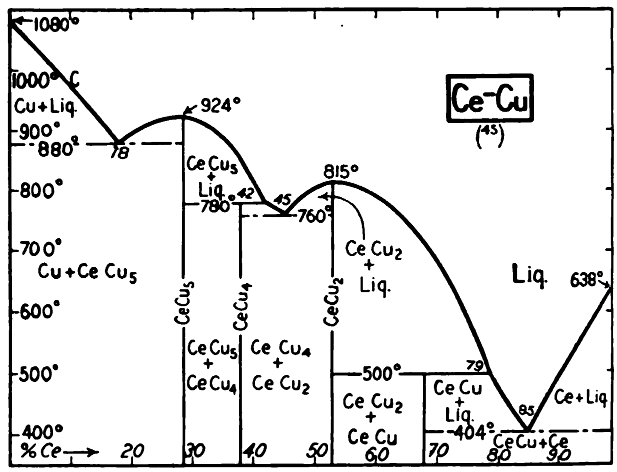

Mg-Cd
(3)
651°
600°C
α + Liq.
Liq.
428°
320°
α [Mg,Cd]
248°
β (MgCd)
α + β
% Mg

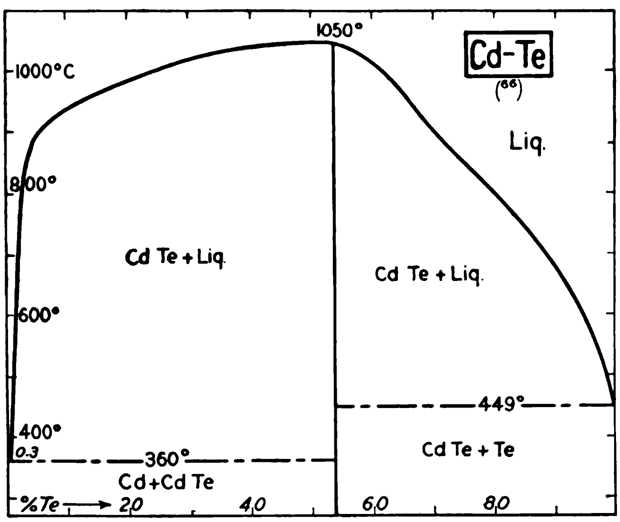

Na-Cd
(70,85)
400°C
α+Liq.
362°
384°
351°
291°
Liq.
α
+
Na Cd₂
200°
Cd
+
Na Cd₆
100°
Na Cd₂ + Liq.
95°
Na Cd₂ + Na
%Na
20
40
60
80

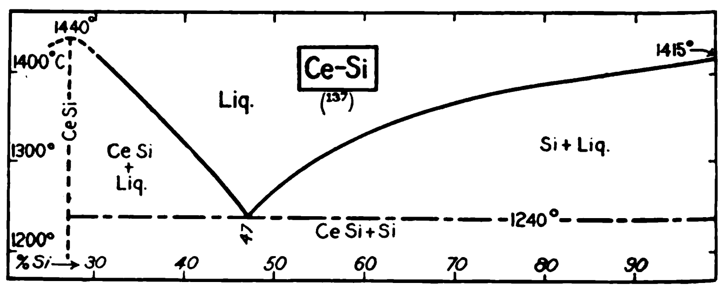

303°
300°C
Liq.
Cd-Tl
(71)
321°
Cd + Liq
200°
α+Liq
28
203°
α (Cd,Tl)
α+Cd
%Cd
20
40
60
80

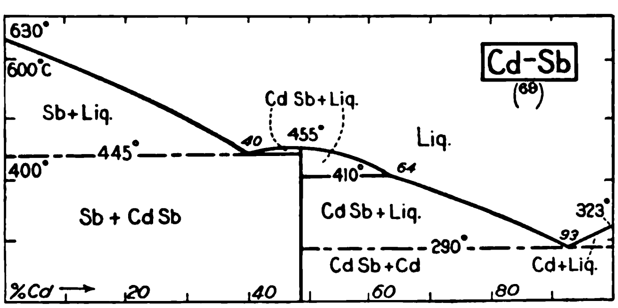

400°C
Cd-Zn
(88)
419°
321°
Liq.
α + Liq
300°
17
263°
Cd+Liq
Cd + α
α (Cd, Zn)
%Zn
20
30
40
50
60
70
80
90

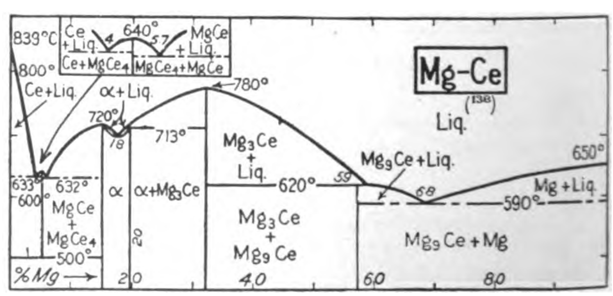

600°C
Ni-Cd
(141)
500°
10
480°
400°
398°
310°
300°
Ni Cd₄ ?
%Ni
10
20

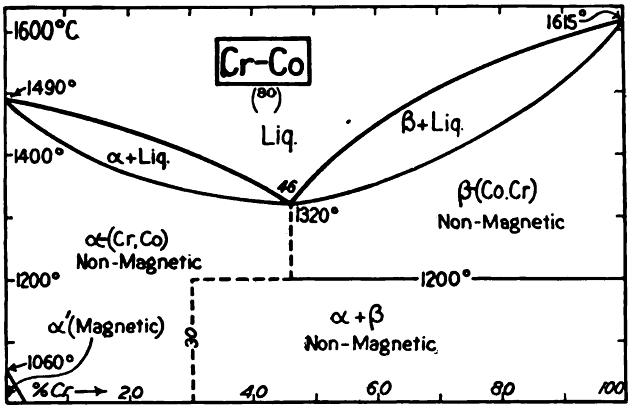

1080°
1000° C
Cu + Liq.
924°
Ce-Cu
(45)
900°
880°
78
815°
Ce Cu₅
+
Liq.
42
45
780°
760°
800°
700°
Cu + Ce Cu₅
Ce Cu₂
+
Liq.
Liq.
638°
Ce Cu₅
Ce Cu₄
Ce Cu₂
600°
Ce Cu₅
+
Ce Cu₄
Ce Cu₄
+
Ce Cu₂
500°
Ce Cu₂
+
Ce Cu
79
Ce Cu
+
Liq.
85
Ce + Liq
404°
400°
Ce Cu + Ce
%Ce
20
30
40
50
60
70
80
90


1050°
Cd-Te
(66)
1000°C
Liq.
800°
Cd Te + Liq.
Cd Te + Liq.
600°
449°
400°
0.3
360°
Cd Te + Te
Cd + Cd Te
%Te
20
40
60
80

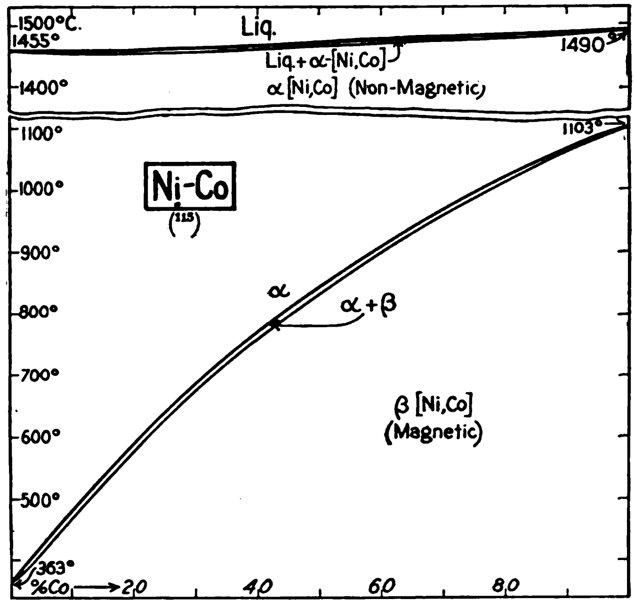

1440°
1400°C
Ce-Si
(137)
1415°
Liq.
Ce Si
1300°
Ce Si
+
Liq.
Si + Liq.
47
1240°
Ce Si + Si
1200°
%Si
30
40
50
60
70
80
90


630°
600°C
Cd-Sb
(68)
Sb + Liq.
Cd Sb + Liq.
455°
Liq.
445°
40
410°
64
400°
Sb + Cd Sb
Cd Sb + Liq.
323°
93
290°
Cd Sb + Cd
Cd + Liq.
%Cd
20
40
60
80

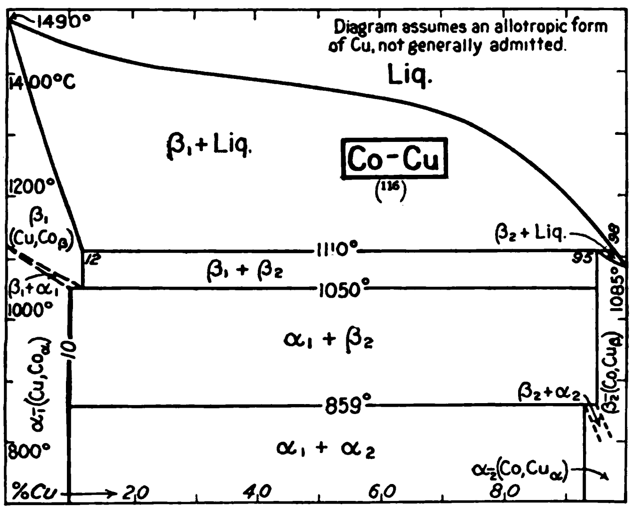

839°C
Ce
+ Liq.
640°
57
Mg Ce
+ Liq.
800°
Ce + Mg Ce₄
Mg Ce₄ + Mg Ce
Mg-Ce
(138)
Ce + Liq.
α + Liq.
780°
Liq.
720°
713°
18
Mg₃ Ce
+
Liq.
Mg₉ Ce + Liq.
650°
633°
632°
600°
α
α + Mg₃ Ce
620°
59
68
Mg + Liq.
590°
Mg Ce
+
Mg Ce₄
Mg₃ Ce
+
Mg₉ Ce
Mg₉ Ce + Mg
500°
%Mg
20
40
60
80



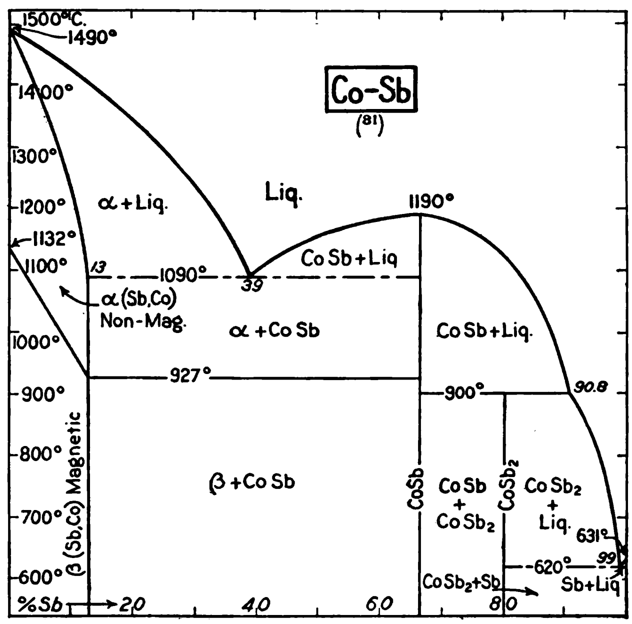
Cr-Co
(80)
1600°C
1615°
1490°
1400°
1200°
1060°
1320°
1200°
Liq.
β+Liq.
α+Liq.
β(Co.Cr)
Non-Magnetic
α(Cr,Co)
Non-Magnetic
α′(Magnetic)
α+β
Non-Magnetic
%Cr → 20 40 60 80 100



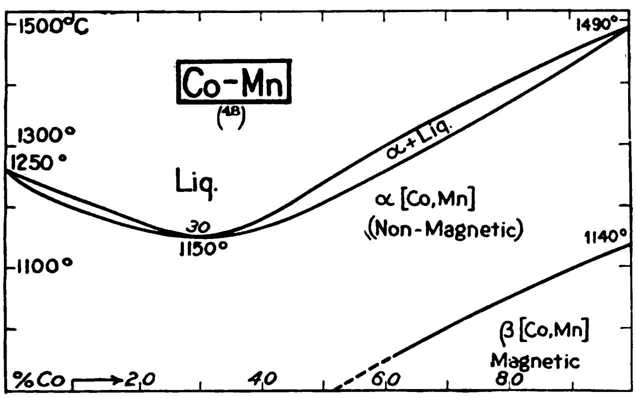
Ni-Co
(115)
1500°C.
1455°
1400°
1490°
Liq.
Liq.+α-[Ni,Co]
α [Ni,Co] (Non-Magnetic)
1100°
1103°
1000°
900°
800°
700°
600°
500°
363°
α
α+β
β [Ni,Co]
(Magnetic)
%Co → 20 40 60 80



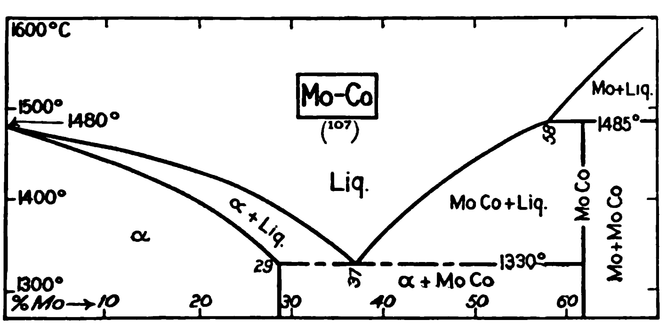
Co-Cu
(116)
Diagram assumes an allotropic form of Cu, not generally admitted.
1490°
1400°C
1200°
1000°
800°
Liq.
β_1+Liq.
β_2+ Liq.
β_1 (Cu,Co$_\beta$)
β_1+α_1
β_1 + β_2
1110°
1050°
1085°
α_1 + β_2
859°
β_2+α_2
α_1 + α_2
α_1(Cu,Co$_\alpha$)
β_2(Co,Cu$_\beta$)
α_2(Co,Cu$_\alpha$)
%Cu → 20 40 60 80



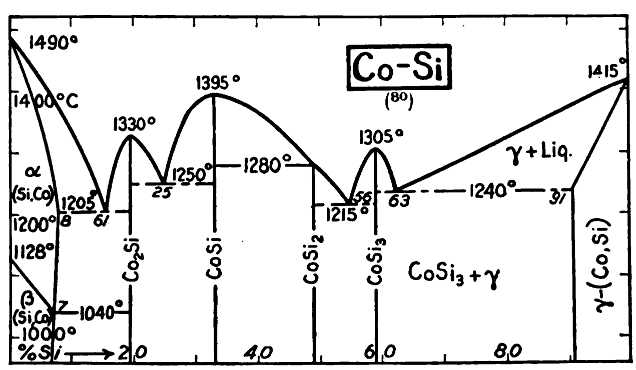
Co-Sb
(81)
1500°C.
1490°
1400°
1300°
1200°
1132°
1100°
1000°
900°
800°
700°
600°
Liq.
α+Liq.
1190°
1090°
CoSb+Liq
α (Sb,Co)
Non-Mag.
α +CoSb
CoSb+Liq.
927°
900°
90.8
β+CoSb
β (Sb,Co) Magnetic
CoSb
CoSb$_2$
CoSb + CoSb$_2$
CoSb$_2$ + Liq.
631°
620°
CoSb$_2$+Sb
Sb+Liq
%Sb → 20 40 60 80



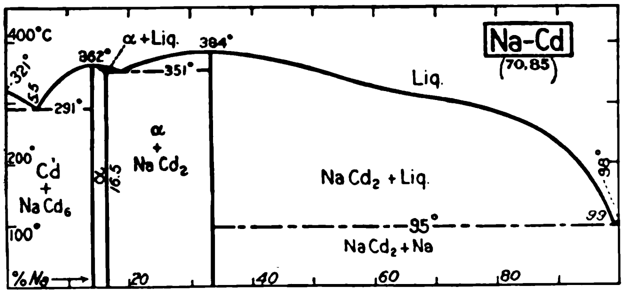
Co-Mn
(48)
1500°C
1490°
1300°
1250°
1100°
Liq.
α+Liq.
α [Co,Mn]
(Non-Magnetic)
1150°
1140°
β [Co,Mn]
Magnetic
%Co → 20 40 60 80

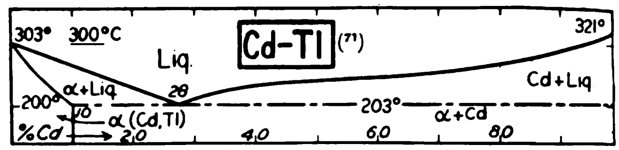


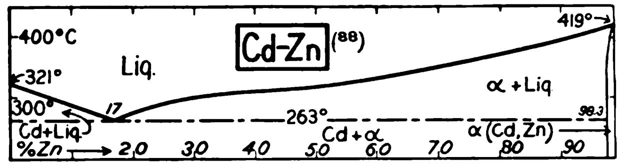
Mo-Co
(107)
1600°C
1500°
1480°
1400°
1300°
Liq.
Mo+Liq.
1485°
α
α+Liq.
Mo Co+Liq.
MoCo
Mo+MoCo
1330°
α + Mo Co
%Mo → 10 20 30 40 50 60

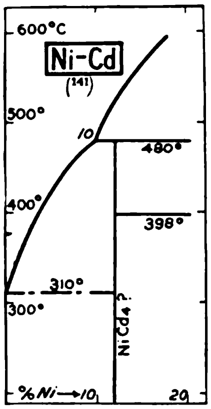


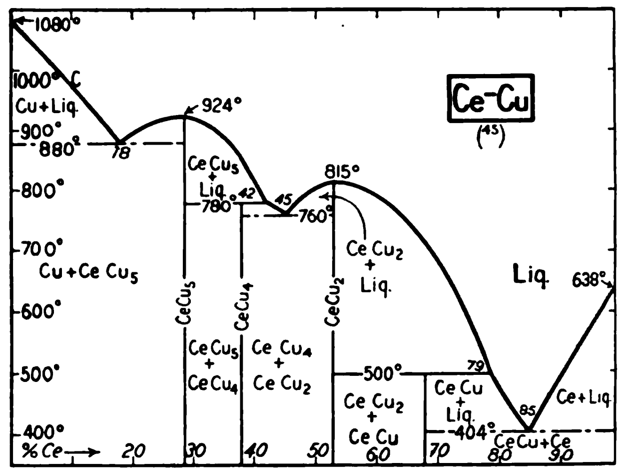
Co-Si
(80)
1490°
1400°C
1395°
1330°
1305°
1415°
1250°
1280°
1205°
1215°
1240°
γ+Liq.
α (Si,Co)
1200°
1128°
β (Si,Co)
1040°
1000°
Co$_2$Si
CoSi
CoSi$_2$
CoSi$_3$
CoSi$_3$+γ
γ-(Co,Si)
%Si → 20 40 60 80

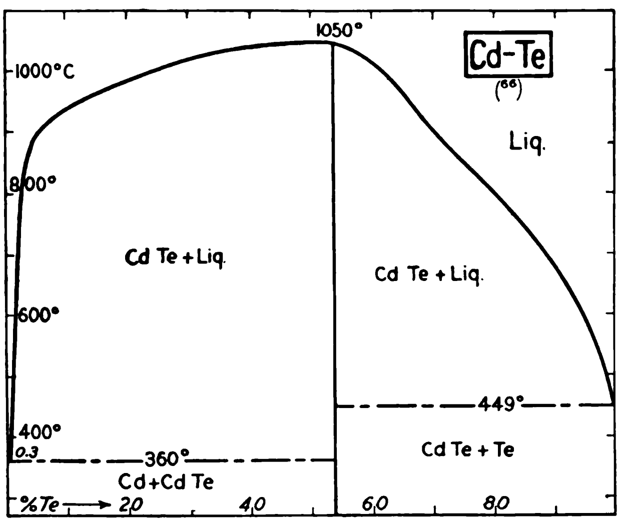

Na-Cd
(70,85)
400°C
α + Liq.
362°
384°
351°
321°
291°
Liq.
α
+
Na Cd₂
200°
Cd
+
Na Cd₆
Na Cd₂ + Liq.
100°
95°
99
Na Cd₂ + Na
%Na
20
40
60
80

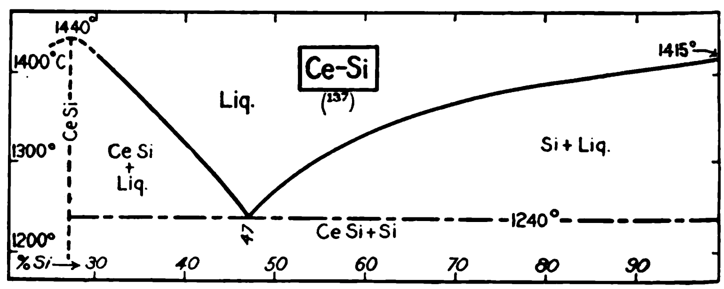

Cd-Tl
(71)
303°
300°C
321°
Liq.
Cd + Liq
200°
α + Liq
28
203°
α + Cd
α (Cd, Tl)
%Cd
20
40
60
80

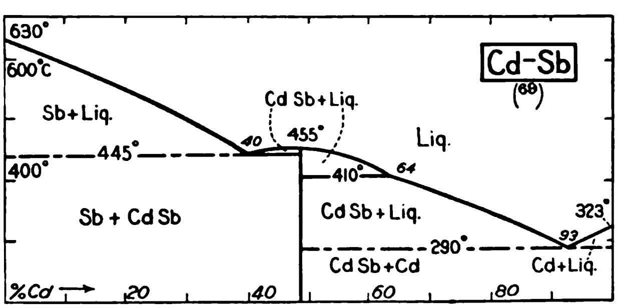

Cd-Zn
(88)
400°C
419°
321°
Liq.
α + Liq
300°
17
263°
Cd + Liq.
Cd + α
α (Cd, Zn)
%Zn
20
30
40
50
60
70
80
90

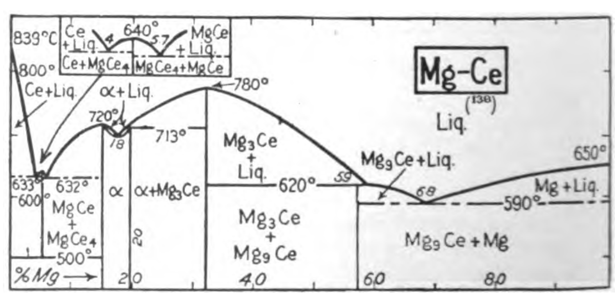

Ni-Cd
(141)
600°C
500°
10
480°
400°
398°
310°
300°
NiCd₄ ?
%Ni
10
20

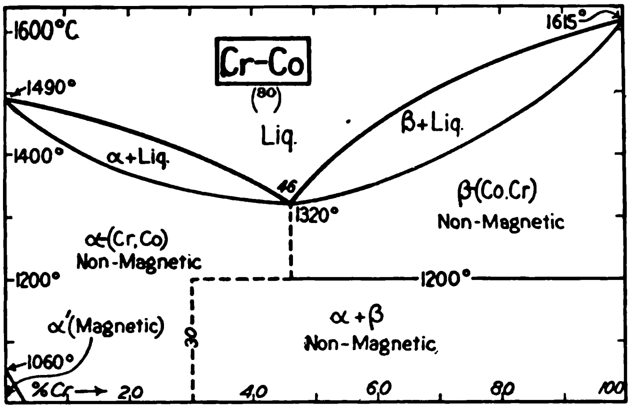

Ce-Cu
(45)
1080°
1000°C
Cu + Liq.
924°
900°
880°
78
815°
Ce Cu₅
+
Liq.
800°
780°
760°
Ce Cu₂
+
Liq.
700°
Cu + Ce Cu₅
Liq.
638°
600°
CeCu₅
CeCu₄
CeCu₂
Ce Cu₅
+
Ce Cu₄
Ce Cu₄
+
Ce Cu₂
500°
500°
Ce Cu
+
Liq.
Ce + Liq.
Ce Cu₂
+
Ce Cu
400°
404°
CeCu + Ce
%Ce
20
30
40
50
60
70
80
90

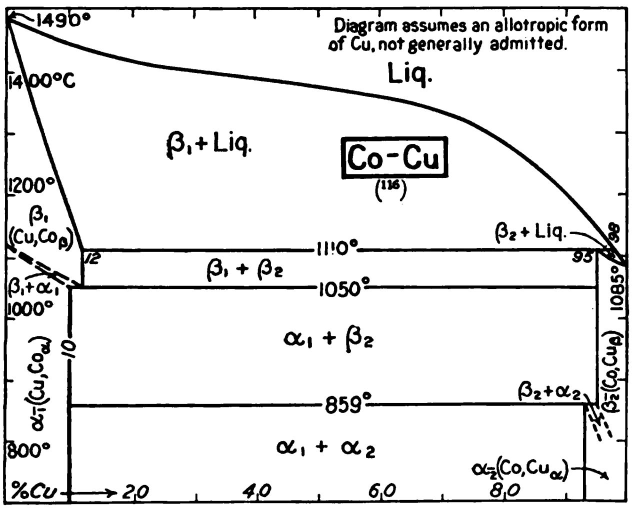

Cd-Te
(66)
1050°
1000°C
Liq.
800°
Cd Te + Liq.
Cd Te + Liq.
600°
449°
400°
0.3
360°
Cd Te + Te
Cd + Cd Te
%Te
20
40
60
80

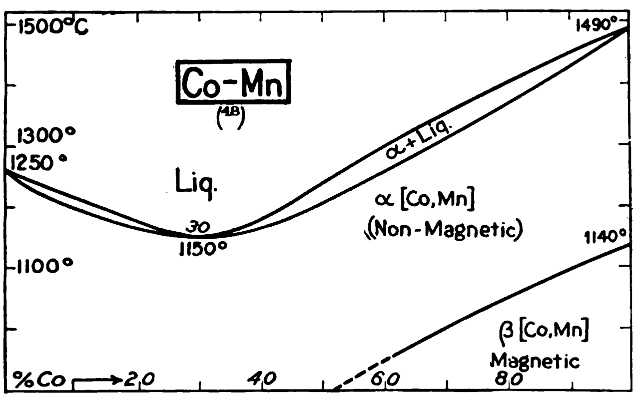

Ce-Si
(137)
1440°
1400°C
1415°
Liq.
Ce Si
1300°
Ce Si
+
Liq.
Si + Liq.
1240°
47
Ce Si + Si
1200°
%Si
30
40
50
60
70
80
90

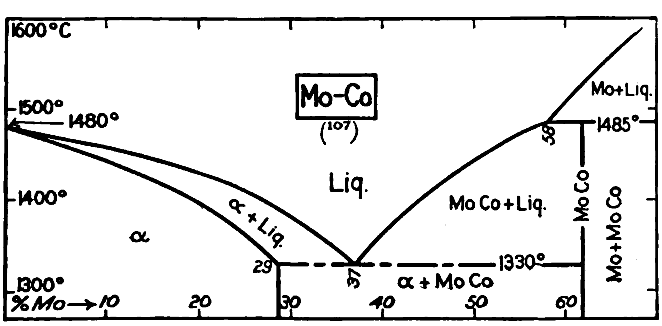

Cd-Sb
(68)
630°
600°C
Cd Sb + Liq.
Sb + Liq.
455°
Liq.
445°
40
400°
410°
64
Sb + Cd Sb
Cd Sb + Liq.
323°
93
290°
Cd Sb + Cd
Cd + Liq.
%Cd
20
40
60
80

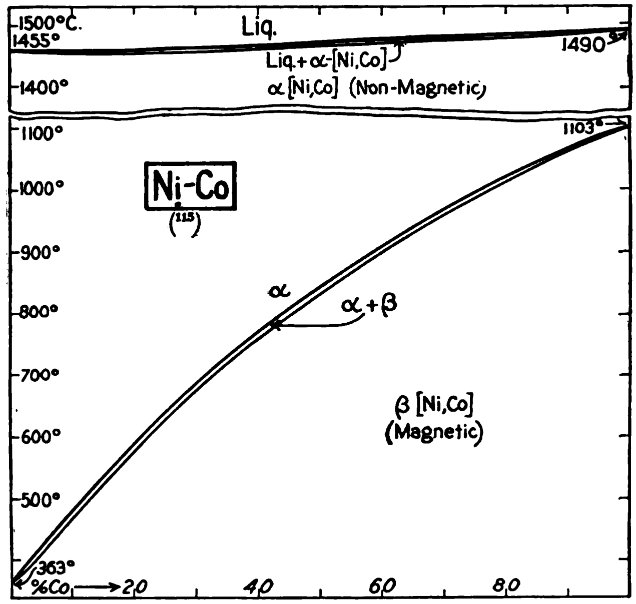

Mg-Ce
(138)
839°C
640°
Ce + Liq.
Mg Ce + Liq.
Ce + MgCe₄
MgCe₄ + MgCe
800°
780°
Ce + Liq.
α + Liq.
720°
713°
Mg₃Ce
+
Liq.
Liq.
Mg₉ Ce + Liq.
650°
633°
632°
620°
Mg + Liq.
600°
Mg Ce
+
Mg Ce₄
α
α + Mg₃Ce
Mg₃ Ce
+
Mg₉ Ce
590°
Mg₉ Ce + Mg
500°
%Mg
20
40
60
80

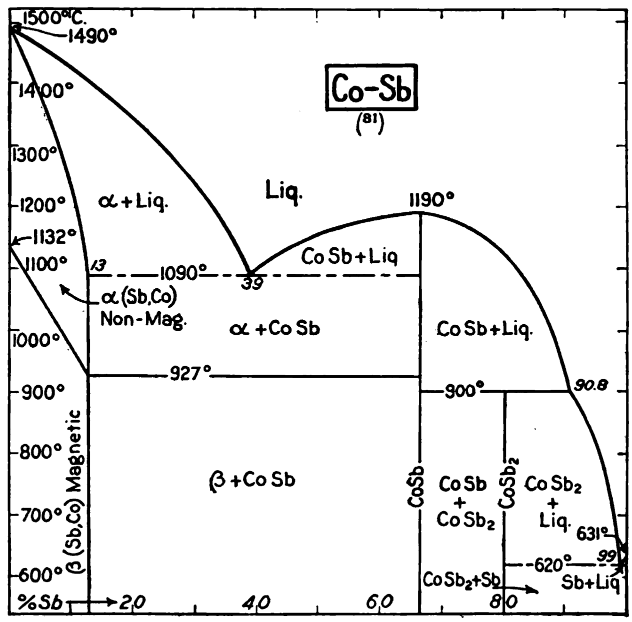

Cr-Co
(80)
1600°C
1615°
1490°
1400°
1200°
1060°
Liq.
β+Liq.
α+Liq.
46
1320°
β(Co.Cr)
Non-Magnetic
α(Cr,Co)
Non-Magnetic
1200°
α′(Magnetic)
30
α+β
Non-Magnetic
%Cr → 20 40 60 80 100

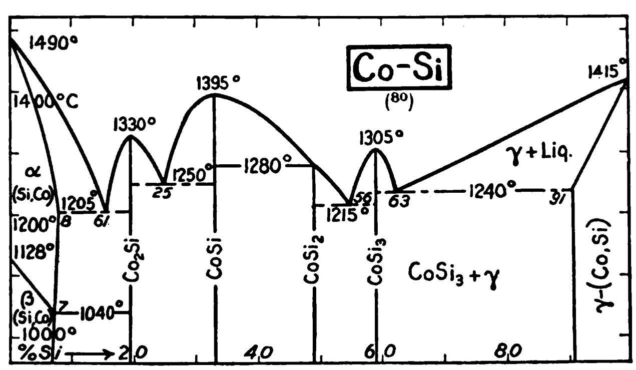

Co-Cu
(116)
Diagram assumes an allotropic form of Cu, not generally admitted.
1490°
1400°C
1200°
1000°
800°
Liq.
β₁+Liq.
β₁ (Cu,Coβ)
β₁+α₁
12
1110°
β₂+Liq.
98
93
β₁ + β₂
1050°
1085°
α₁ + β₂
10
α₁(Cu,Coα)
β₂(Co,Cuβ)
β₂+α₂
859°
α₁ + α₂
α₂(Co,Cuα)
%Cu → 20 40 60 80

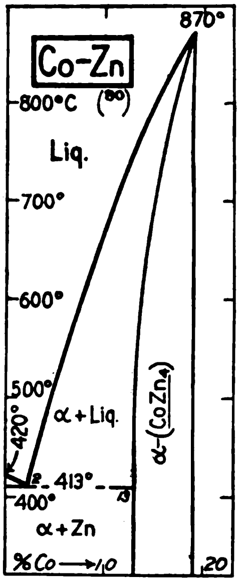

Co-Mn
(48)
1500°C
1490°
1300°
1250°
1100°
Liq.
α+Liq.
α [Co,Mn]
(Non-Magnetic)
30
1150°
1140°
β [Co,Mn]
Magnetic
%Co → 20 40 60 80


Mo-Co
(107)
1600°C
1500°
1480°
1400°
1300°
Liq.
Mo+Liq.
1485°
58
Mo Co+Liq.
α
α+Liq.
29
37
1330°
α + Mo Co
Mo Co
Mo+Mo Co
%Mo → 10 20 30 40 50 60

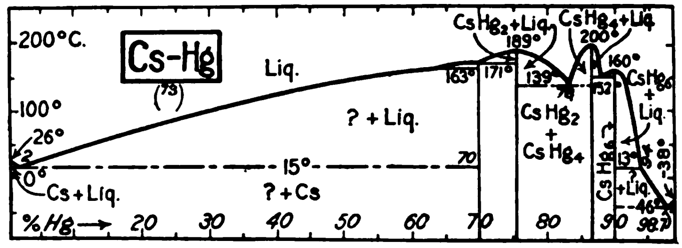

1500°C.
1455°
Liq.
Liq.+α-[Ni,Co]
1490°
1400°
α [Ni,Co] (Non-Magnetic)
Ni-Co
(115)
1100°
1103°
1000°
900°
800°
700°
600°
500°
363°
α
α+β
β [Ni,Co]
(Magnetic)
%Co → 20 40 60 80


Co-Sb
(81)
1500°C.
1490°
1400°
1300°
1200°
1132°
1100°
1000°
900°
800°
700°
600°
Liq.
α+Liq.
1190°
Co Sb+Liq
13
1090°
39
α (Sb,Co)
Non-Mag.
α +Co Sb
Co Sb+Liq.
927°
900°
90.8
β (Sb,Co) Magnetic
β +Co Sb
CoSb
CoSb₂
Co Sb + Co Sb₂
Co Sb₂ + Liq.
631°
620°
99
CoSb₂+Sb
Sb+Liq
%Sb → 20 40 60 80

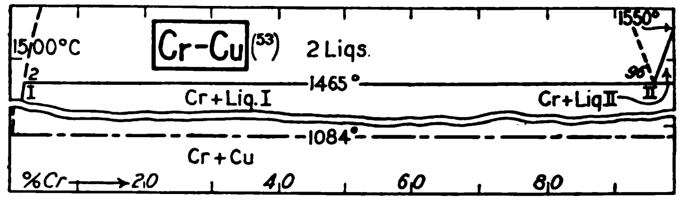

Co-Si
(80)
1490°
1400°C
1395°
1330°
1305°
1415°
γ+Liq.
α (Si,Co)
1205°
1250°
1280°
1240°
8
61
25
1215°
56
63
37
1200°
1128°
β (Si,Co)
1040°
1000°
Co₂Si
CoSi
CoSi₂
CoSi₃
CoSi₃+γ
γ-(Co,Si)
%Si → 20 40 60 80



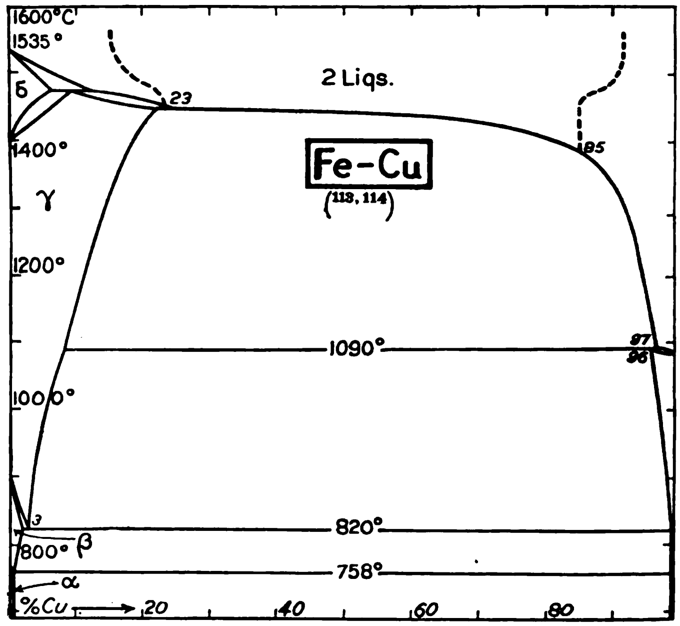
Co-Zn
(80)
870°
800°C
Liq.
700°
600°
500°
420°
α+Liq.
α-(CoZn4)
413°
400°
α+Zn
%Co →10
20



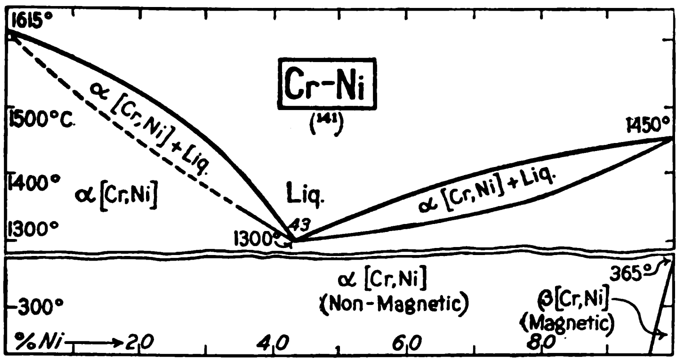
Cs-Hg
(73)
200°C.
Liq.
CsHg2+Liq.
CsHg4+Liq.
189°
200°
160°
163°
171°
139
152°
CsHg6+Liq.
100°
26°
? + Liq.
CsHg2 + CsHg4
15°
70
0°
Cs+Liq.
?+Cs
CsHg6
13°
-46°
98.7
%Hg → 20 30 40 50 60 70 80 90



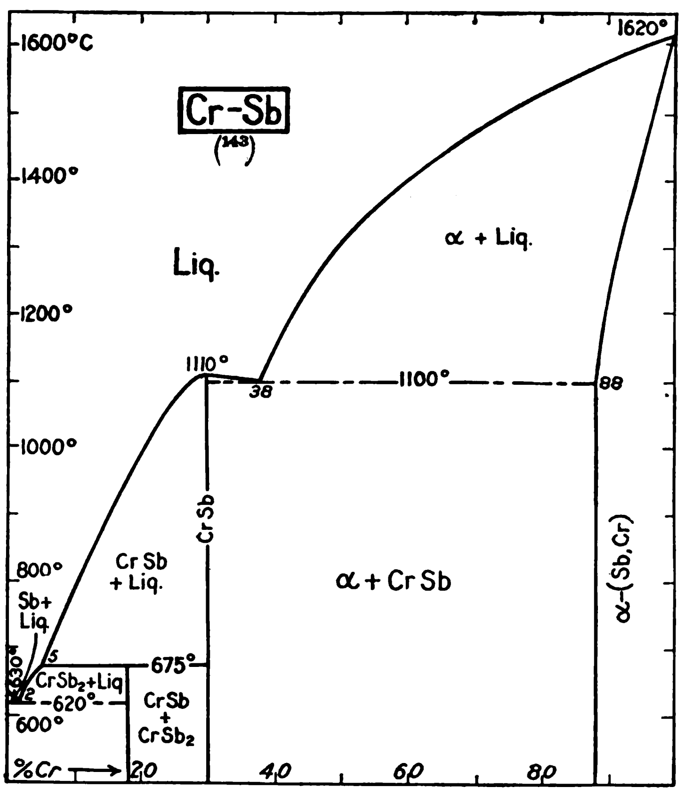
Cr-Cu
(53)
1550°
1500°C
2 Liqs.
1465°
I
II
Cr+Liq.I
Cr+LiqII
1084°
Cr+Cu
%Cr → 20 40 60 80



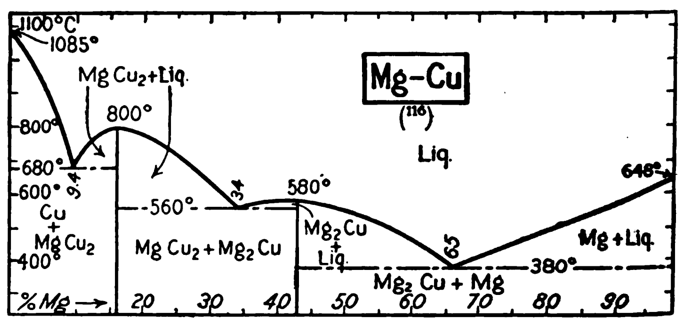
Fe-Cu
(113, 114)
1600°C
1535°
δ
2 Liqs.
23
85
1400°
γ
1200°
1090°
97
96
1000°
820°
800°
β
758°
α
%Cu → 20 40 60 80



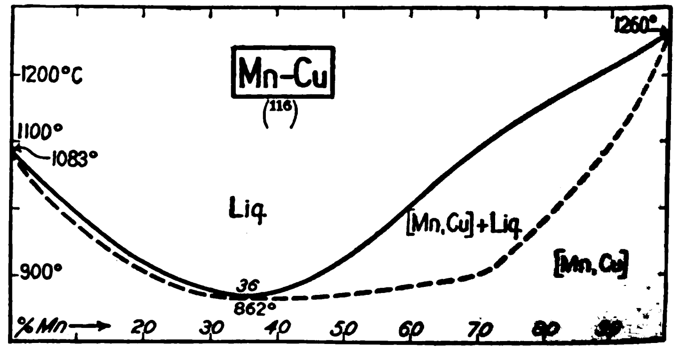
Cr-Ni
(141)
1615°
1500°C.
α[Cr,Ni]+Liq.
1450°
1400°
α[Cr,Ni]
Liq.
α[Cr,Ni]+Liq.
1300°
43
α[Cr,Ni] (Non-Magnetic)
365°
β[Cr,Ni] (Magnetic)
300°
%Ni → 20 40 60 80



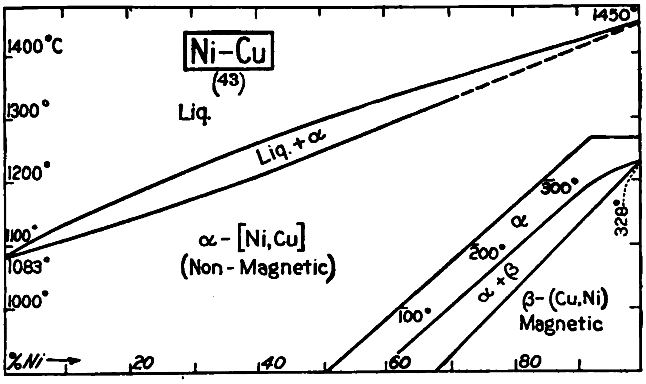
Cr-Sb
(143)
1600°C
1620°
1400°
Liq.
α + Liq.
1200°
1110°
1100°
38
88
1000°
CrSb
α+CrSb
α-(Sb,Cr)
800°
CrSb + Liq.
Sb+ Liq.
675°
CrSb2+Liq
620°
630°
600°
CrSb + CrSb2
%Cr → 20 40 60 80

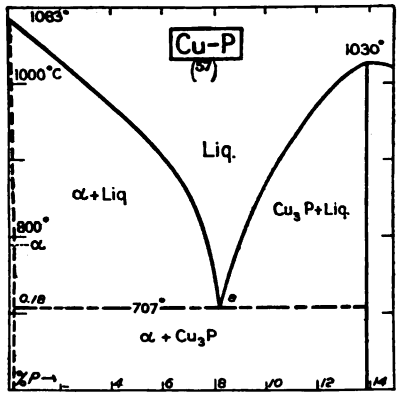


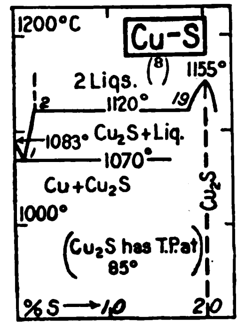
Mg-Cu
(116)
1100°C
1085°
MgCu2+Liq.
800°
Liq.
680°
600°
Cu + MgCu2
560°
580°
648°
Mg2Cu + Liq.
Mg+Liq.
MgCu2+Mg2Cu
380°
400°
Mg2Cu + Mg
%Mg → 20 30 40 50 60 70 80 90

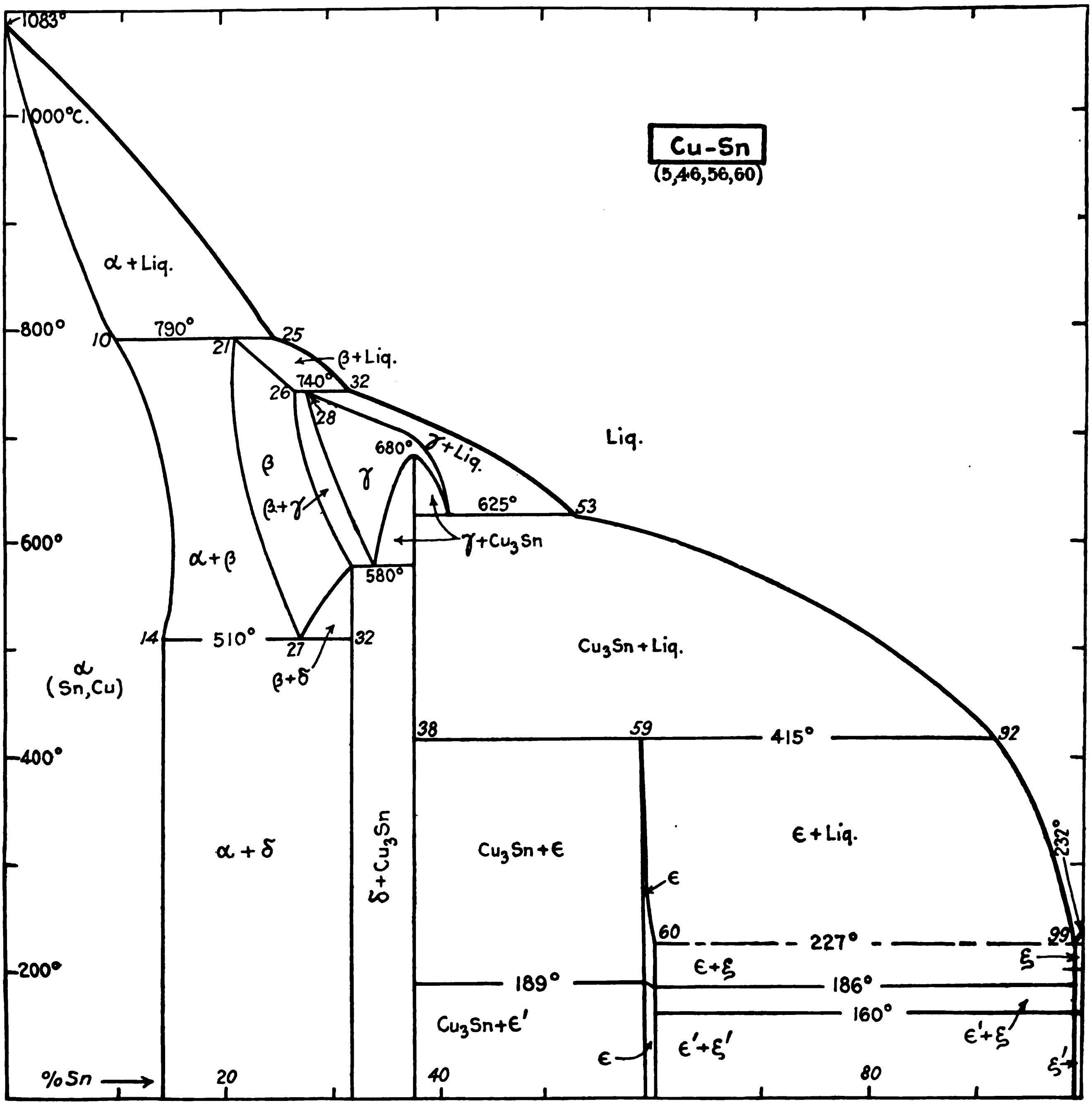


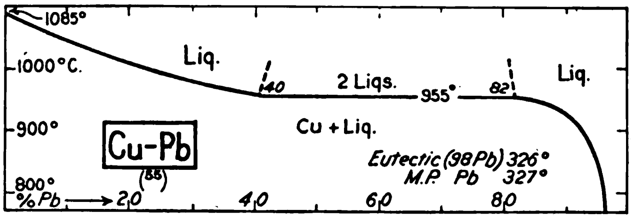
Mn-Cu
(116)
1260°
1200°C
1100°
1083°
Liq.
[Mn,Cu]+Liq.
[Mn,Cu]
900°
36
862°
%Mn → 20 30 40 50 60 70 80 90

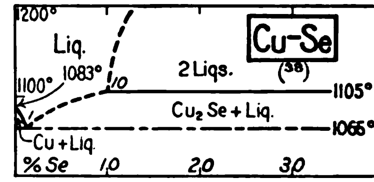

Ni-Cu
(43)
1400°C
1300°
1200°
1100°
1083°
1000°
1450°
Liq.
Liq.+α
α-[Ni,Cu]
(Non-Magnetic)
α
α+β
β-(Cu,Ni)
Magnetic
300°
200°
100°
328°
%Ni→
20
40
60
80

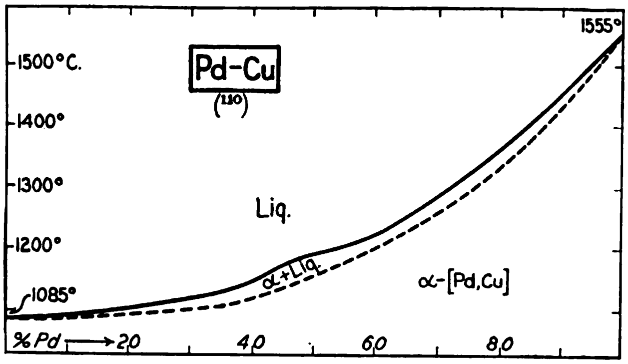

Cu-P
(57)
1083°
1000°C
800°
1030°
Liq.
α+Liq
Cu_3P+Liq.
707°
α + Cu_3P
%P→
4
6
8
10
12
14

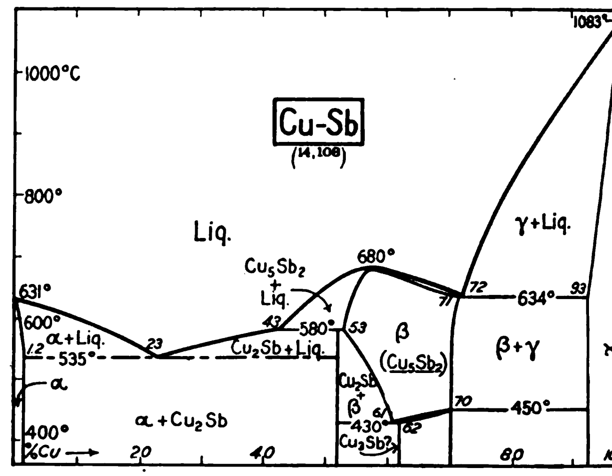

Cu-S
(8)
1200°C
1155°
2 Liqs.
1120°
1083°
Cu_2S+Liq.
1070°
Cu+Cu_2S
1000°
(Cu_2S has T.P. at 85°)
Cu_2S
%S→
10
20

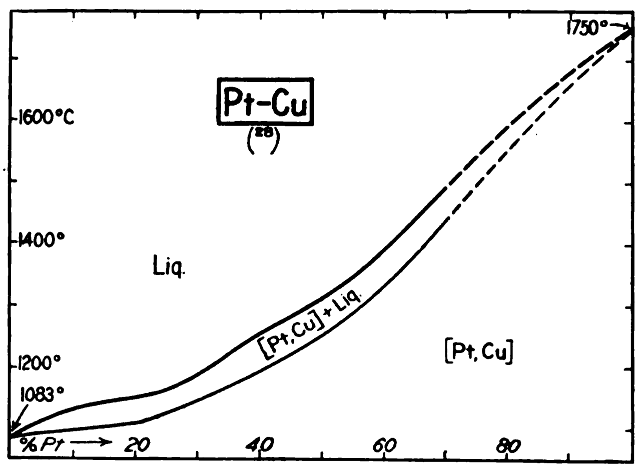

Cu-Sn
(5,46,56,60)
1083°
1000°C.
800°
600°
400°
200°
α + Liq.
790°
10
21
25
β+Liq.
740°
26
32
28
Liq.
680°
γ+Liq.
β
γ
β+γ
625°
53
γ+Cu_3Sn
α+β
580°
14
510°
27
32
β+δ
α
(Sn,Cu)
Cu_3Sn+Liq.
38
59
415°
92
α + δ
δ+Cu_3Sn
Cu_3Sn+ε
ε+Liq.
232°
ε
60
227°
99
ε+ξ
ξ
189°
186°
160°
Cu_3Sn+ε′
ε′+ξ′
ε′+ξ
ξ′
%Sn
20
40
80

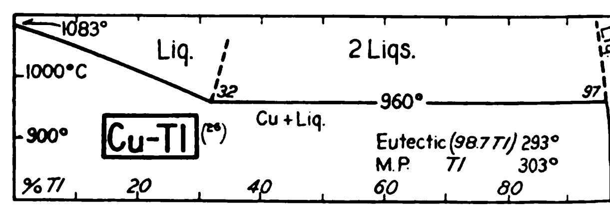

1085°
1000°C.
900°
800°
%Pb → 20 40 60 80
Liq.
2 Liqs.
955°
40
82
Liq.
Cu + Liq.
Cu-Pb
(88)
Eutectic (98 Pb) 326°
M.P. Pb 327°

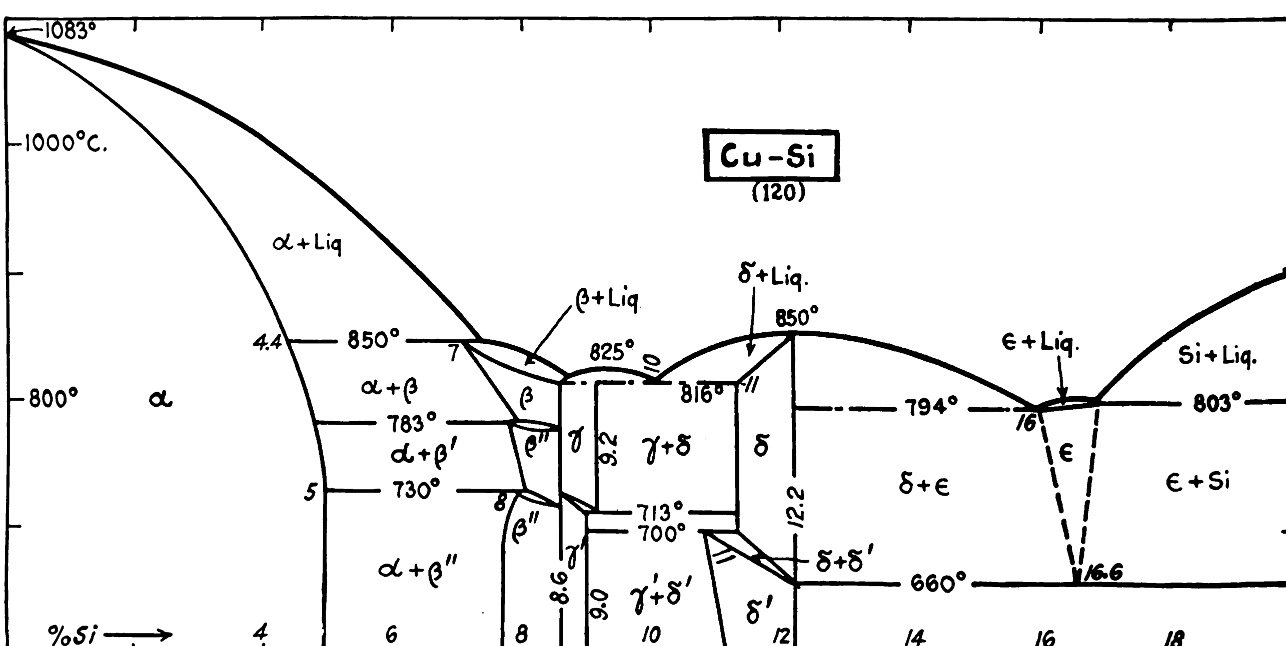

1200°
Liq.
1100°
1083°
10
2 Liqs.
Cu-Se
(38)
1105°
Cu_2Se + Liq.
1065°
Cu + Liq.
%Se 10 20 30

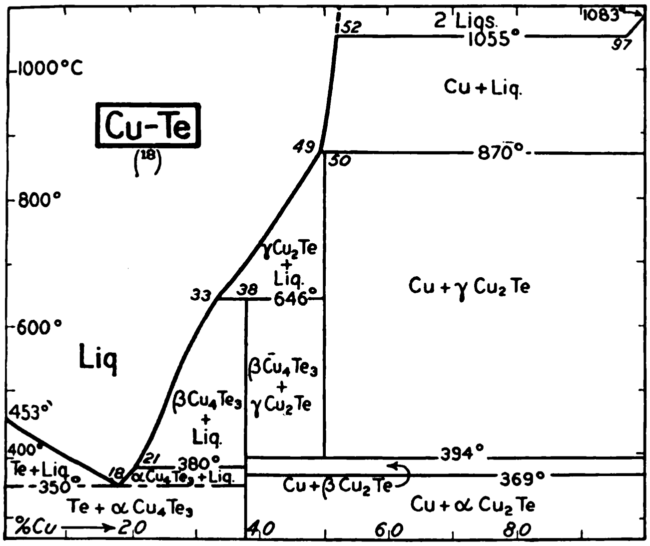

1555°
1500°C.
1400°
1300°
1200°
1085°
Pd-Cu
(110)
Liq.
α+Liq.
α-[Pd,Cu]
%Pd → 20 40 60 80

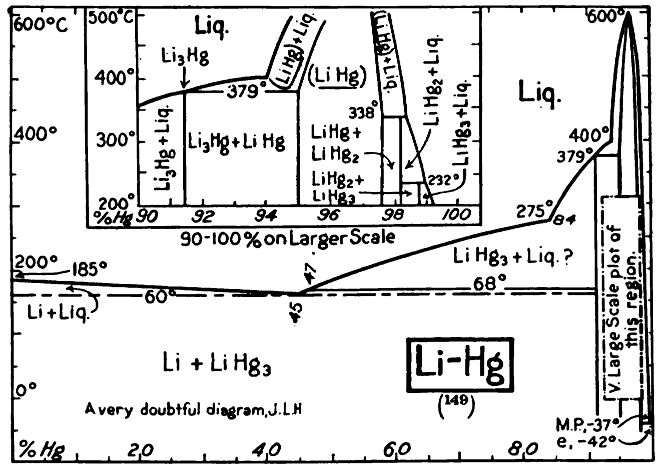

1083°
1000°C
800°
600°
400°
Cu-Sb
(14,108)
Liq.
γ+Liq.
Cu_5Sb_2 + Liq.
680°
631°
72
634°
93
71
43
580°
53
β (Cu_5Sb_2)
β+γ
γ
α+Liq.
1.2
535°
23
Cu_2Sb+Liq.
α
α + Cu_2Sb
Cu_2Sb + β
61
430°
Cu_2Sb?
62
70
450°
%Cu → 20 40 80 100

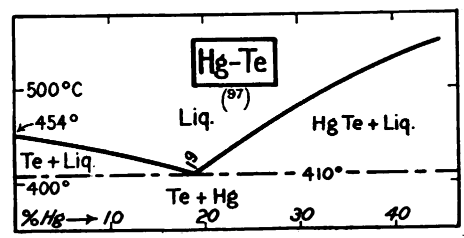

1750°
1600°C
1400°
1200°
1083°
Pt-Cu
(28)
Liq.
[Pt,Cu]+Liq.
[Pt,Cu]
%Pt → 20 40 60 80

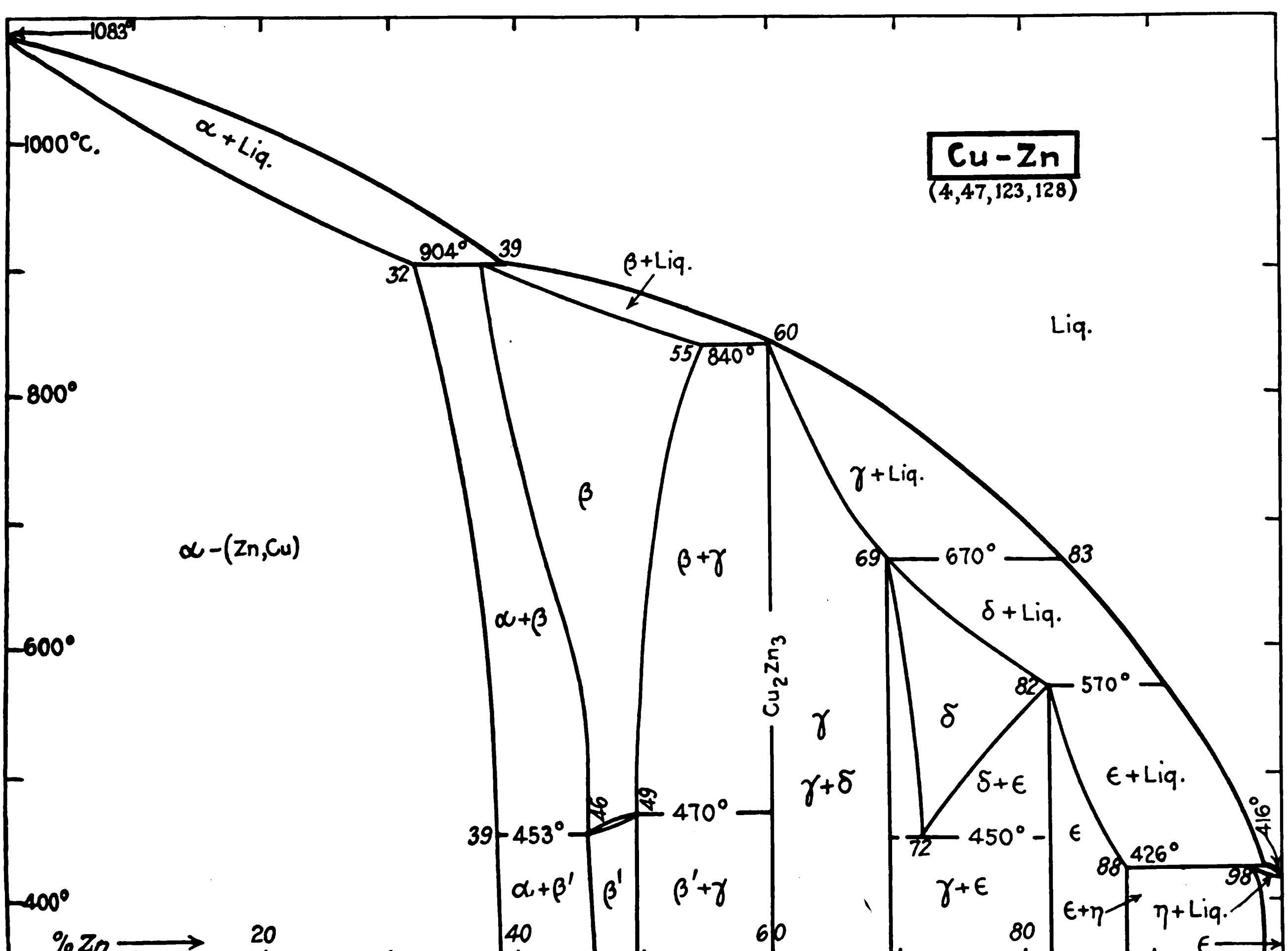

1083°
1000°C
900°
Liq.
2 Liqs.
Liq.
32
960°
97
Cu + Liq.
Cu-Tl
(26)
Eutectic (98.7 Tl) 293°
M.P. Tl 303°
%Tl 20 40 60 80

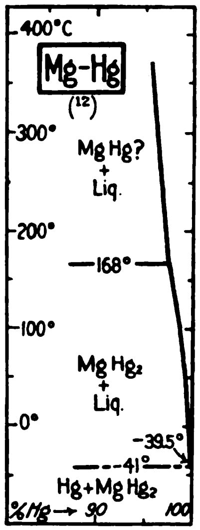

1083°
1000°C.
800°
Cu-Si
(120)
α+Liq
β+Liq
δ+Liq.
850°
ε+Liq.
Si+Liq.
4.4
850°
7
825°
10
816°
11
794°
16
803°
α
α+β
β
783°
α+β′
β″
γ
9.2
γ+δ
δ
δ+ε
ε
ε+Si
5
730°
8
713°
700°
12.2
β″
γ′
δ+δ′
α+β″
8.6
9.0
γ′+δ′
δ′
660°
16.6
%Si → 4 6 8 10 12 14 16 18

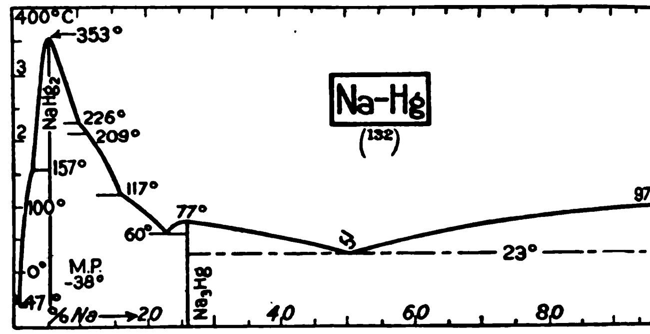

Cu-Te
(18)
1000°C
800°
600°
453°
400°
2 Liqs.
1083°
1055°
97
52
Cu + Liq.
49
50
870°
γCu_2Te + Liq.
33
38
646°
Cu + γ Cu_2 Te
Liq
βCu_4Te_3 + Liq.
βCu_4Te_3 + γCu_2Te
21
380°
18
αCu_4Te_3+Liq.
394°
369°
Te+Liq.
-350°
Cu+βCu_2Te
Cu + α Cu_2 Te
Te + α Cu_4Te_3
%Cu → 20
40
60
80

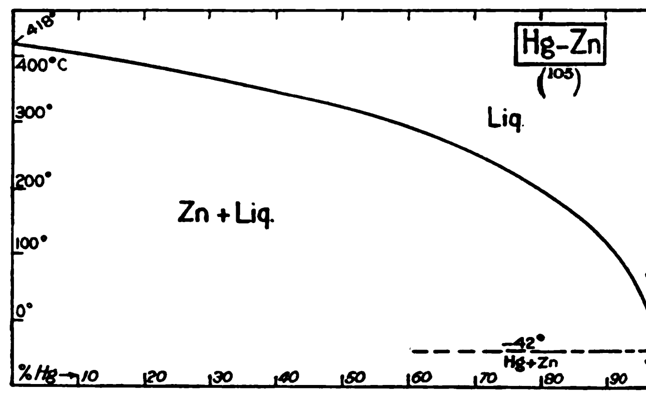

600°C
500°C
Liq.
Li_3Hg
(Li Hg)+Liq.
(Li Hg)
$LiHg_2$+Liq.
$LiHg_3$+Liq.
400°
379°
338°
300°
Li_3Hg+Liq.
Li_3Hg+Li Hg
LiHg + $LiHg_2$
$LiHg_2$+ $LiHg_3$
232°
200°
%Hg 90
92
94
96
98
100
90-100% on Larger Scale
Liq.
400°
379°
275°
84
Li Hg_3 + Liq. ?
68°
200°
185°
47
60°
45
Li+Liq.
Li + Li Hg_3
Li-Hg
(149)
V. Large Scale plot of this region.
0°
A very doubtful diagram, J.L.H
M.P.,-37°
e, -42°
%Hg
20
40
60
80

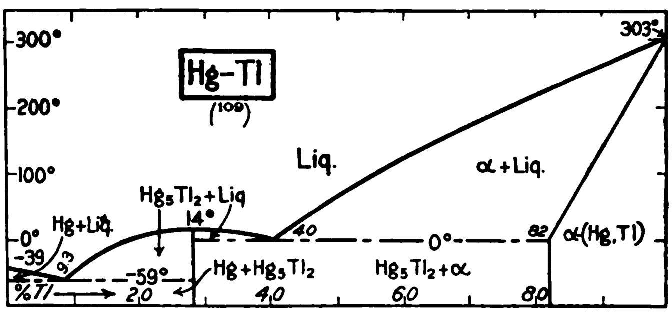

Hg-Te
(97)
500°C
454°
Liq.
Hg Te + Liq.
Te + Liq.
19
410°
400°
Te + Hg
%Hg → 10
20
30
40

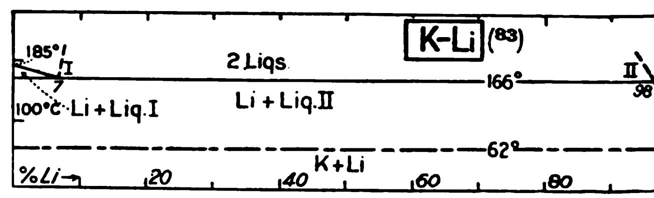

1083°
1000°C.
α + Liq.
Cu - Zn
(4,47,123,128)
904°
39
32
β+Liq.
60
55
840°
Liq.
800°
β
γ + Liq.
α -(Zn,Cu)
β+γ
69
670°
83
δ + Liq.
α+β
600°
Cu_2Zn_3
82
570°
γ
δ
γ+δ
δ+ε
ε + Liq.
46
49
470°
416°
39
453°
72
450°
ε
88
426°
98
400°
α+β′
β′
β′+γ
γ+ε
ε+η
η+Liq.
ε
% Zn →
20
40
60
80

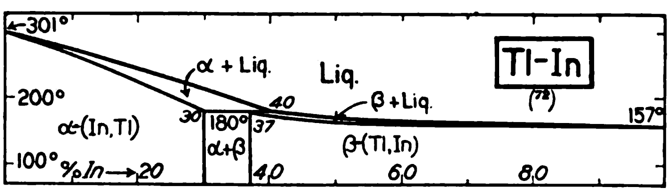

400°C
Mg-Hg
(12)
300°
MgHg?
+
Liq.
200°
168°
100°
MgHg₂
+
Liq.
0°
-39.5°
-41°
Hg+MgHg₂
%Hg → 90
100

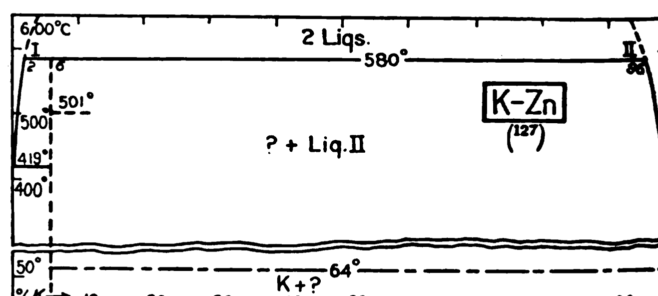

400°C
353°
NaHg₂
226°
209°
157°
117°
100°
77°
60°
0°
M.P.
-38°
-47°
Na-Hg
(132)
97°
23°
Na₃Hg
%Na → 20
40
60
80

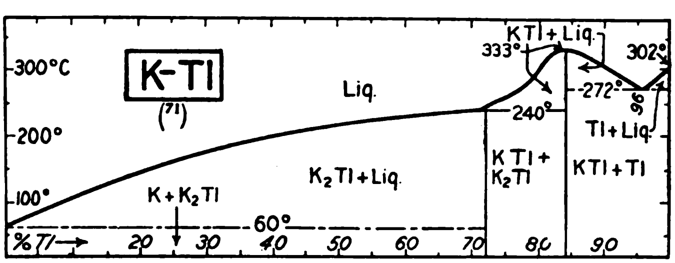

418°
400°C
300°
200°
100°
0°
Hg-Zn
(105)
Liq.
Zn + Liq.
-42°
Hg+Zn
%Hg → 10
20
30
40
50
60
70
80
90

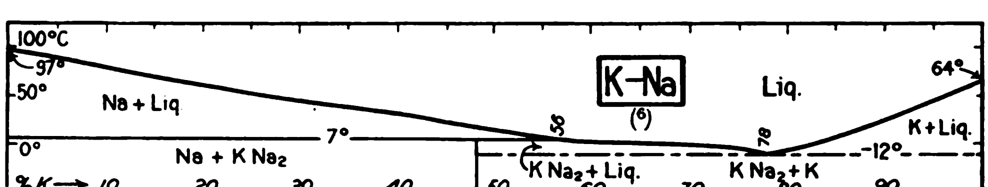

300°
200°
100°
0°
-39
Hg-Tl
(109)
Liq.
α + Liq.
303°
Hg₅Tl₂ + Liq
14°
Hg+Liq.
-59°
Hg+Hg₅Tl₂
Hg₅Tl₂+α
α-(Hg,Tl)
0°
40
82
%Tl → 20
40
60
80

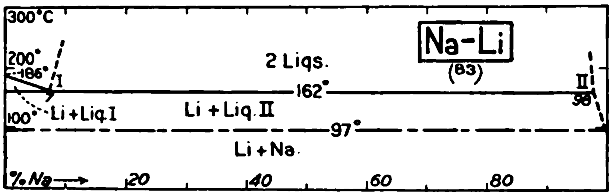

185°
I
2 Liqs.
K-Li
(83)
II
166°
98
100°C
Li + Liq. I
Li + Liq. II
62°
K+Li
%Li →
20
40
60
80

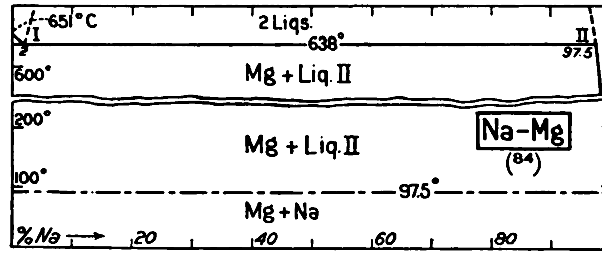

301°
α + Liq.
Liq.
Tl-In
(72)
200°
α-(In,Tl)
30
40
180°
37
β + Liq.
157°
α+β
β-(Tl,In)
100°
%In → 20
40
60
80

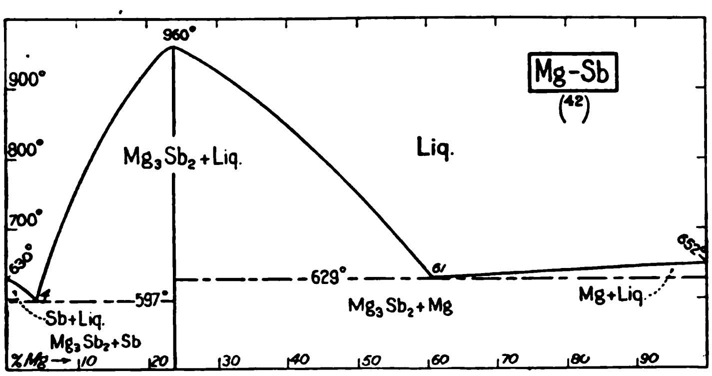

600°C
I
2 Liqs.
580°
II
501°
500
419°
400°
K-Zn
(127)
? + Liq. II
50°
64°
K + ?
%K → 10
20
30
40
50
60
70
80
90

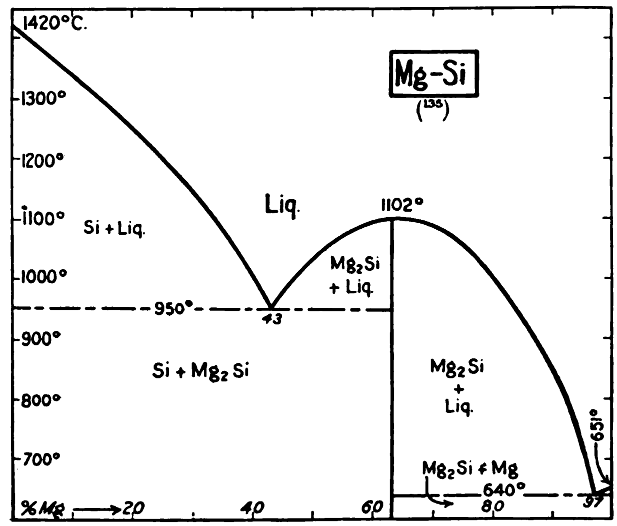

300°C
K-Tl
(71)
Liq.
KTl + Liq.
333°
302°
-272°
240°
Tl+Liq.
200°
K₂Tl+Liq.
KTl + K₂Tl
KTl+Tl
100°
K+K₂Tl
60°
%Tl →
20
30
40
50
60
70
80
90

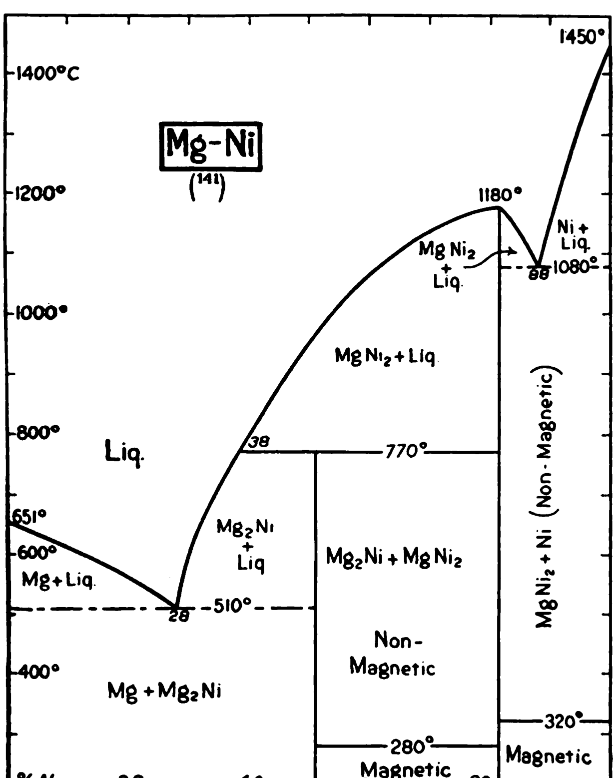

100°C
97°
50°
Na + Liq.
K-Na
(6)
Liq.
64°
K+Liq.
7°
56
78
-12°
0°
Na + KNa₂
KNa₂ + Liq.
KNa₂ + K
%K → 10
20
30
40
50
60
70
80
90

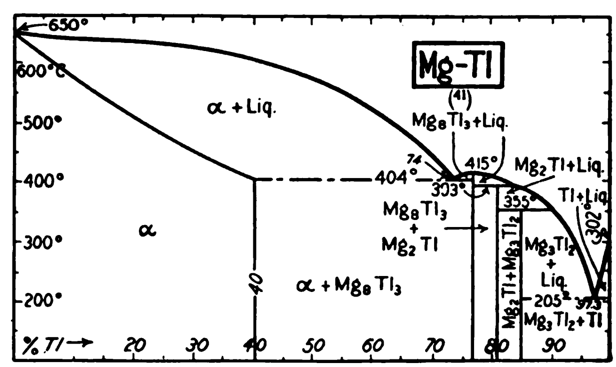

Na-Li
(83)
300°C
200°
186°
100°
2 Liqs.
162°
Li + Liq. I
Li + Liq. II
97°
Li + Na
98
% Na →
20
40
60
80

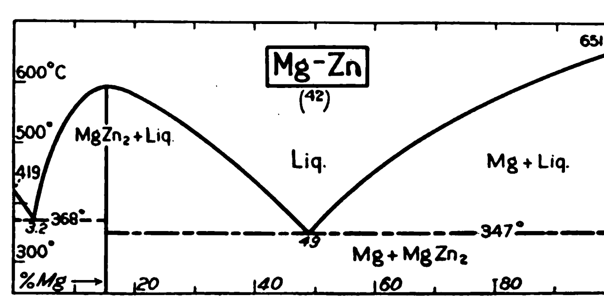

651°C
2 Liqs.
638°
97.5
600°
Mg + Liq. II
200°
Mg + Liq. II
Na-Mg
(84)
100°
97.5°
Mg + Na
% Na →
20
40
60
80

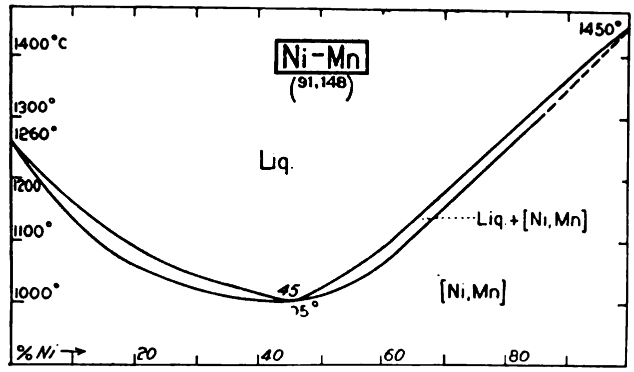

960°
Mg-Sb
(42)
900°
800°
Mg₃Sb₂ + Liq.
Liq.
700°
630°
629°
61
652°
597°
Mg₃Sb₂ + Mg
Mg + Liq.
Sb + Liq.
Mg₃Sb₂ + Sb
% Mg →
10
20
30
40
50
60
70
80
90

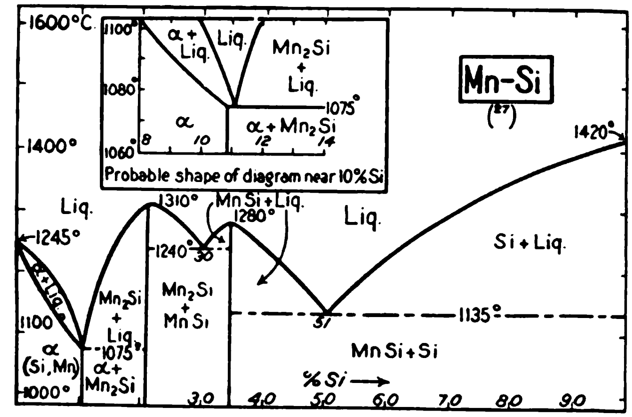

1420°C.
Mg-Si
(135)
1300°
1200°
Liq.
1102°
1100°
Si + Liq.
Mg₂Si + Liq.
1000°
950°
43
900°
Si + Mg₂Si
Mg₂Si + Liq.
800°
651°
700°
Mg₂Si + Mg
640°
% Mg → 20
40
60
80
97

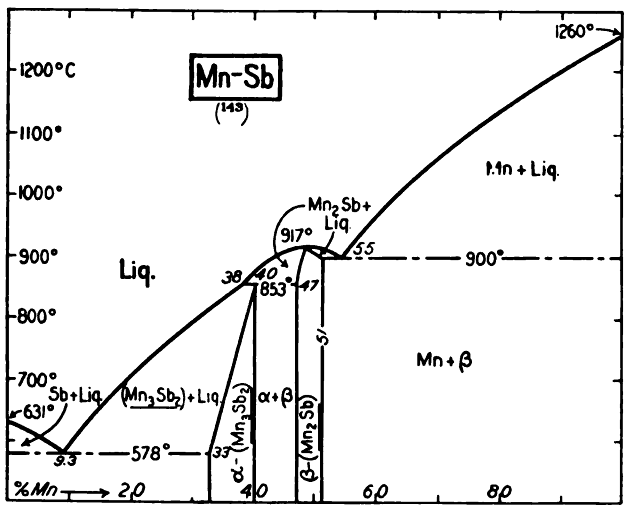

1450°
1400°C
Mg-Ni
(141)
1200°
1180°
Mg Ni₂ + Liq.
Ni + Liq.
1080°
88
1000°
Mg Ni₂ + Liq
MgNi₂ + Ni (Non-Magnetic)
800°
Liq.
38
770°
651°
600°
Mg + Liq.
Mg₂Ni + Liq
Mg₂Ni + Mg Ni₂
510°
28
Non-Magnetic
400°
Mg + Mg₂Ni
320°
280°
Magnetic
Magnetic
% Ni → 20
40
60
80

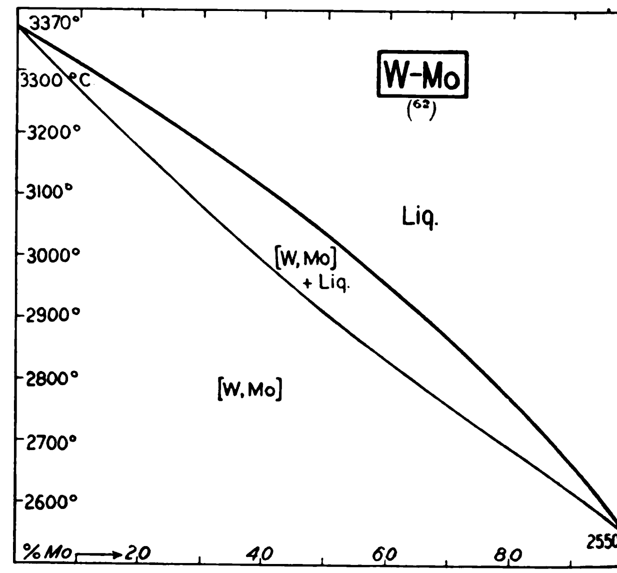

650°
600°C
Mg-Tl
(41)
500°
α + Liq.
Mg₈Tl₃ + Liq.
415°
Mg₂Tl + Liq.
74
404°
303°
355°
Tl + Liq.
400°
Mg₈Tl₃ + Mg₂Tl
302°
300°
α
Mg₃Tl₂ + Liq.
200°
α + Mg₈Tl₃
Mg₂Tl + Mg₃Tl₂
205°
Mg₃Tl₂ + Tl
% Tl →
20
30
40
50
60
70
80
90

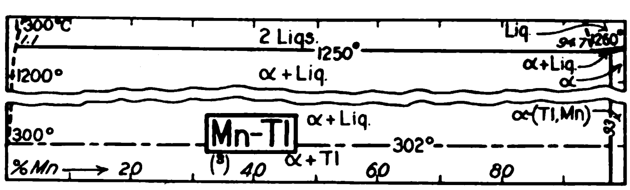

651°
Mg-Zn
(42)
600°C
500°
MgZn₂ + Liq.
Liq.
Mg + Liq.
419
368°
3.2
347°
49
300°
Mg + MgZn₂
% Mg →
20
40
60
80

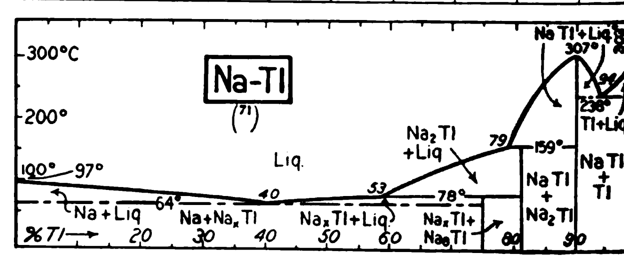

Ni-Mn
(91, 148)
1400°C
1450°
1300°
1260°
1200
1100°
1000°
Liq.
Liq. + [Ni, Mn]
[Ni, Mn]
45
%Ni
20
40
60
80

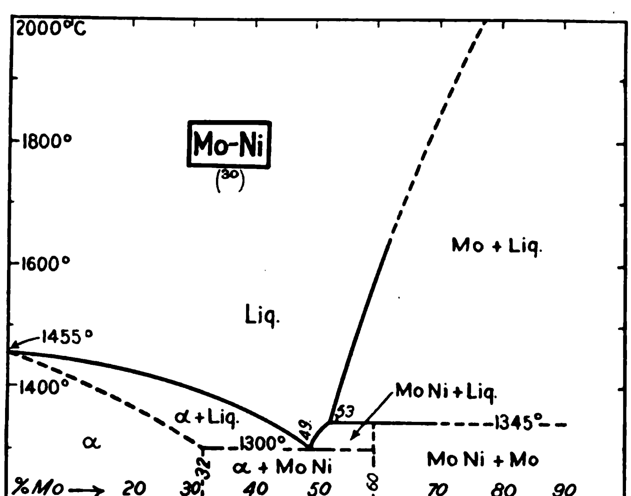

1600°C
Mn-Si
(27)
1100°
1080°
1060°
α + Liq.
Liq.
Mn2Si + Liq.
1075°
α
α + Mn2Si
8
10
12
14
Probable shape of diagram near 10% Si
1400°
1420°
Liq.
1245°
1310°
Mn Si + Liq.
1280°
1240°
30
Liq.
Si + Liq.
Mn2Si + Liq.
Mn2Si + Mn Si
1100
1075°
α (Si, Mn)
α + Mn2Si
1000°
37
1135°
Mn Si + Si
% Si
3.0
4.0
5.0
6.0
7.0
8.0
9.0

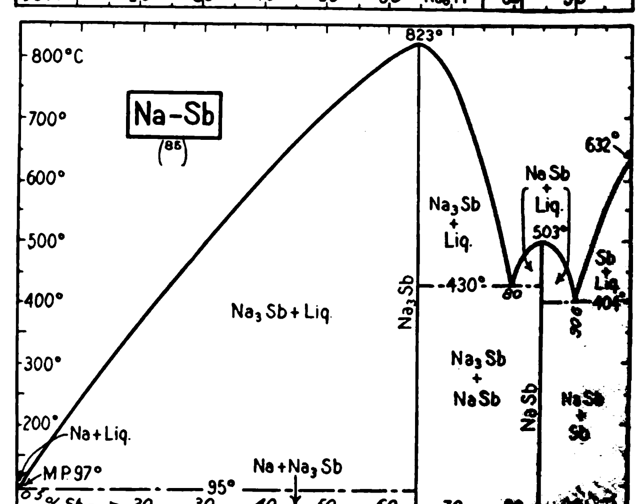

Mn-Sb
(143)
1260°
1200°C
1100°
1000°
Mn + Liq.
Mn2Sb + Liq.
917°
900°
55
900°
Liq.
38
40
853°
47
800°
51
Mn + β
700°
Sb + Liq.
(Mn3Sb2) + Liq.
α + β
631°
578°
9.3
33
α-(Mn3Sb2)
β-(Mn2Sb)
%Mn
20
40
60
80

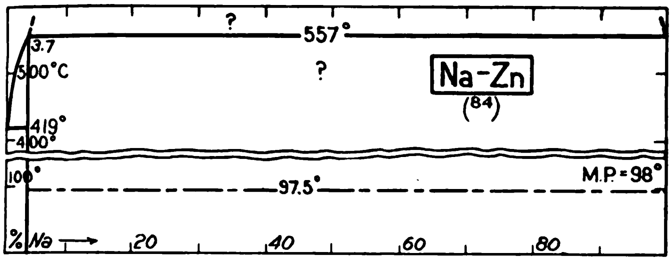

3370°
3300°C
W-Mo
(62)
3200°
3100°
Liq.
3000°
[W, Mo] + Liq.
2900°
2800°
[W, Mo]
2700°
2600°
2550°
% Mo
20
40
60
80

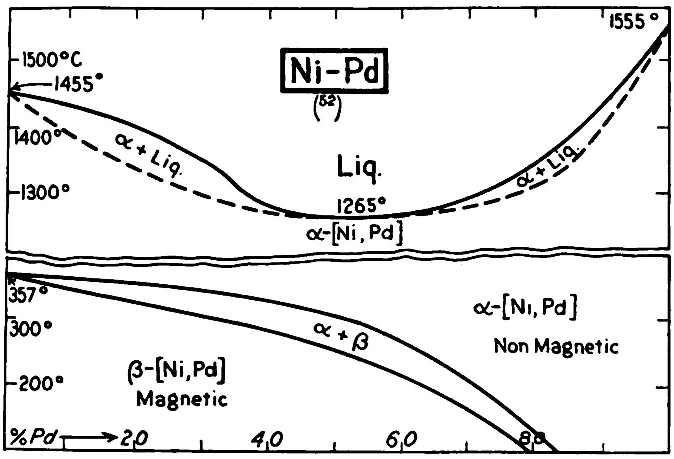

1300°C
2 Liqs.
Liq.
1250°
1260°
α + Liq.
1200°
α + Liq.
α
α(Tl, Mn)
300°
Mn-Tl
(8)
α + Liq.
302°
α + Tl
%Mn
20
40
60
80

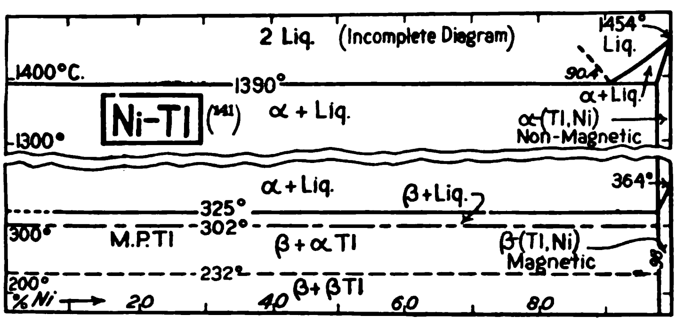

Na Tl + Liq.
307°
300°C
Na-Tl
(71)
200°
Na2Tl + Liq
79
159°
Tl + Liq
Liq.
100°
97°
40
53
78°
Na Tl + Tl
Na Tl + Na2Tl
Na + Liq
64°
Na + NaxTl
NaxTl + Liq.
NaxTl + Na2Tl
% Tl
20
30
40
50
60
80
90

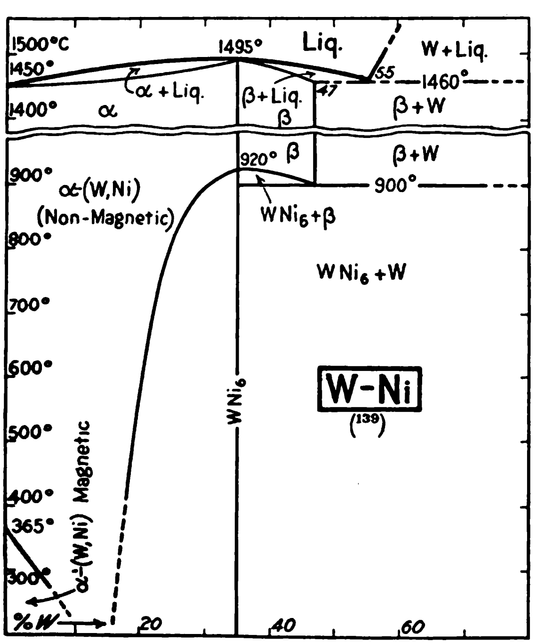

2000°C
Mo-Ni
(30)
1800°
1600°
Mo + Liq.
Liq.
1455°
1400°
Mo Ni + Liq.
53
α + Liq.
49
1345°
α
1300°
32
α + Mo Ni
60
Mo Ni + Mo
%Mo
20
30
40
50
70
80
90

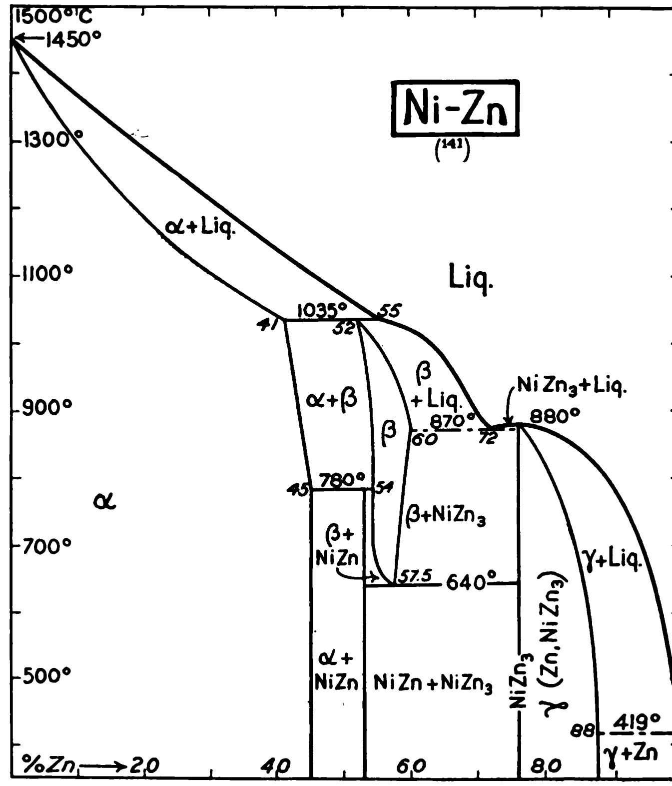

823°
800°C
Na-Sb
(85)
700°
632°
600°
Na Sb + Liq.
Na3Sb + Liq.
503°
500°
430°
400°
Na3 Sb + Liq.
Na3Sb
Sb + Liq.
404°
300°
Na3 Sb + Na Sb
Na Sb
Na Sb + Sb
200°
Na + Liq.
M.P. 97°
Na + Na3 Sb
95°
% Sb
20
30
40
50
60
70
80

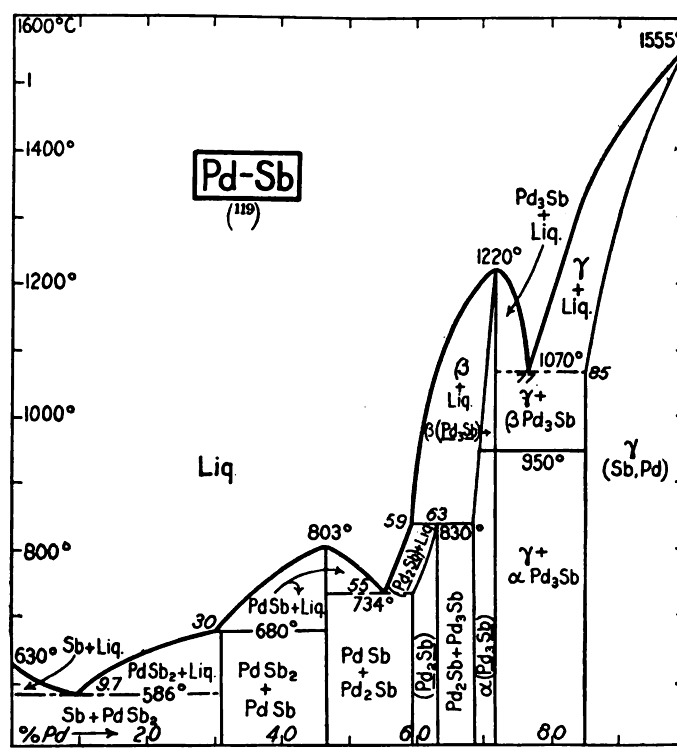

Na-Zn
(84)
557°
?
3.7
500°C
419°
400°
100°
97.5°
M.P.=98°
% Na → 20 40 60 80

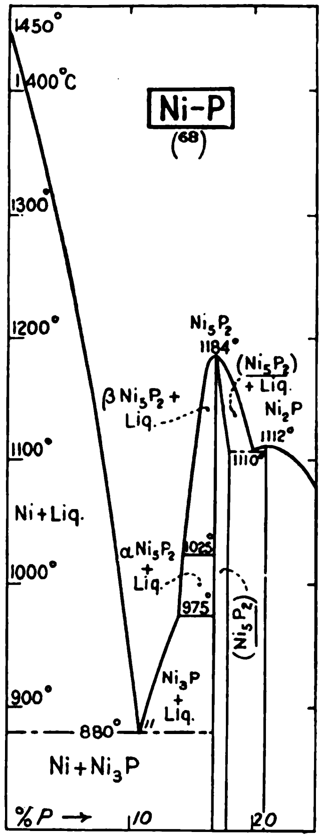

Ni-Pd
(52)
1555°
1500°C
1455°
1400°
1300°
α + Liq.
Liq.
1265°
α-[Ni, Pd]
357°
300°
200°
α + β
α-[Ni, Pd]
Non Magnetic
β-[Ni, Pd]
Magnetic
% Pd → 20 40 60 80

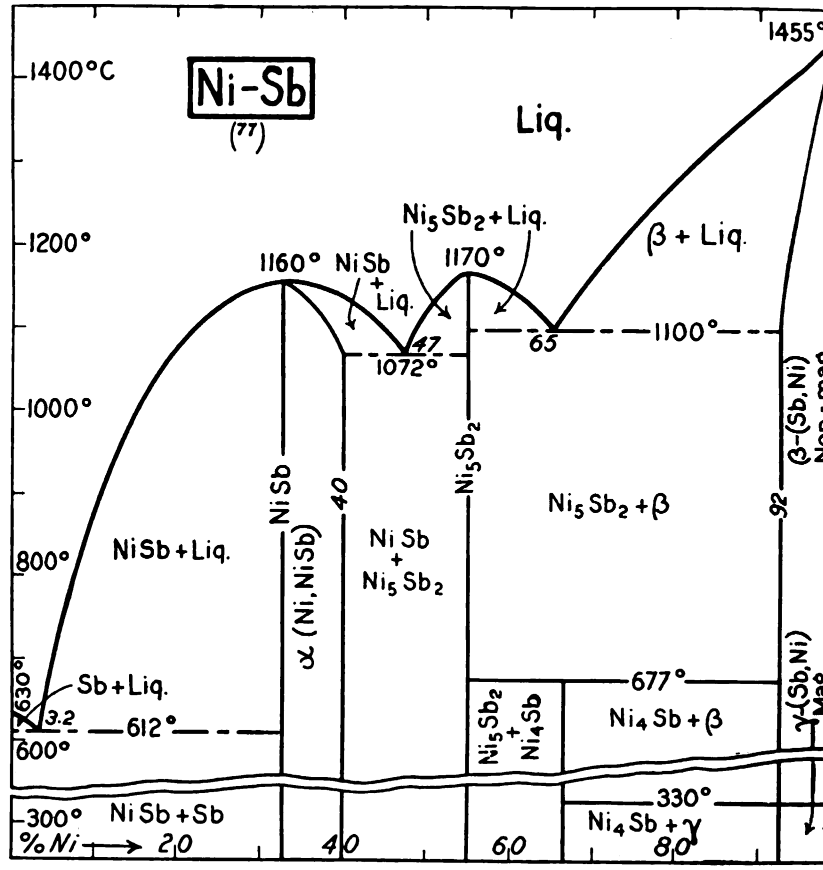

2 Liq. (Incomplete Diagram)
1454°
Liq.
1400°C.
1390°
90.4
α+Liq.
Ni-Tl
(141)
α + Liq.
α-(Tl, Ni)
Non-Magnetic
1300°
α + Liq.
β+Liq.
364°
325°
302°
300°
M.P.Tl
β + α Tl
β-(Tl, Ni)
Magnetic
200°
232°
β+ β Tl
% Ni → 20 40 60 80

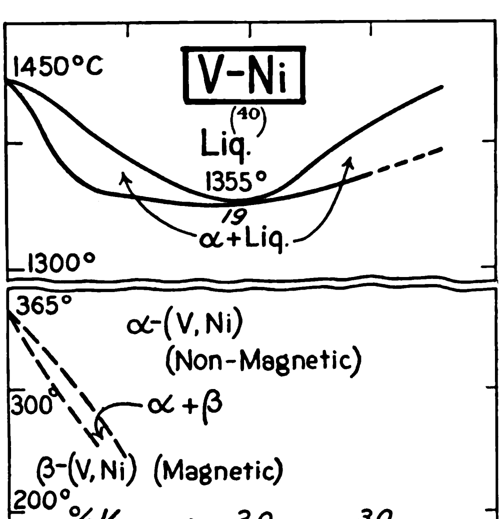

1500°C
1495°
Liq.
W+Liq.
1450°
α + Liq.
55
1460°
1400°
α
β+Liq.
β
47
β+W
900°
920°
β
β+W
900°
α-(W,Ni)
(Non-Magnetic)
WNi6+β
800°
WNi6 +W
700°
600°
WNi6
W-Ni
(139)
500°
400°
α-(W,Ni) Magnetic
365°
300°
% W → 20 40 60

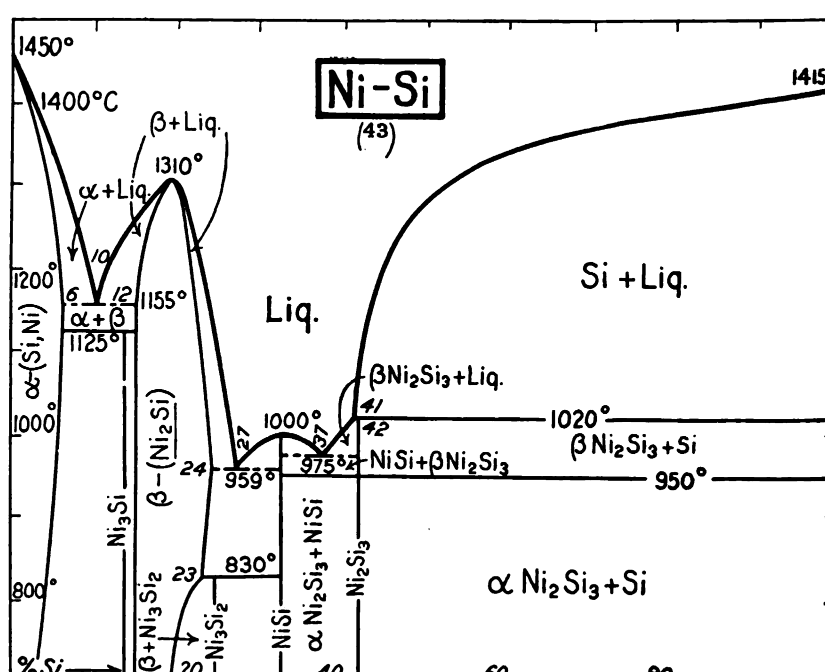

1500°C
1450°
Ni-Zn
(141)
1300°
α+Liq.
1100°
Liq.
1035°
55
41
32
α+β
β
+ Liq.
Ni Zn3+Liq.
870°
880°
900°
β
60
72
45
780°
54
β+NiZn3
α
700°
β+
NiZn
57.5
640°
γ+Liq.
γ (Zn, NiZn3)
α +
NiZn
NiZn + NiZn3
NiZn3
500°
88
419°
γ+Zn
% Zn → 20 40 60 80

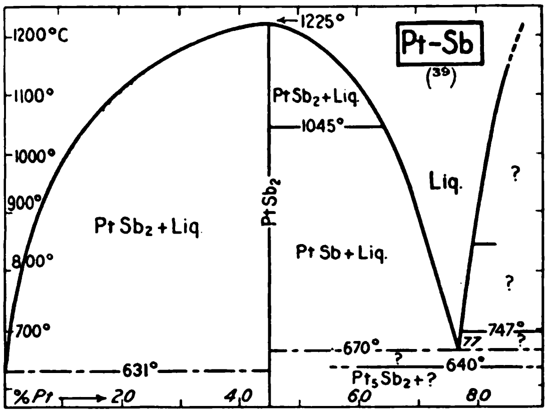

1600°C
1555°
1400°
Pd-Sb
(119)
Pd3Sb
+
Liq.
1220°
γ
+
Liq.
1200°
β
+
Liq.
1070°
85
γ+
β Pd3Sb
β(Pd3Sb)
1000°
Liq.
950°
γ
(Sb,Pd)
803°
59
63
830°
800°
γ+
α Pd3Sb
55
734°
PdSb+Liq.
30
680°
630°
Sb+Liq.
PdSb2+Liq.
9.7
586°
Pd Sb2
+
Pd Sb
Pd Sb
+
Pd2 Sb
(Pd2Sb)
Pd2Sb+Pd3Sb
α(Pd3Sb)
Sb + Pd Sb2
% Pd → 20 40 60 80

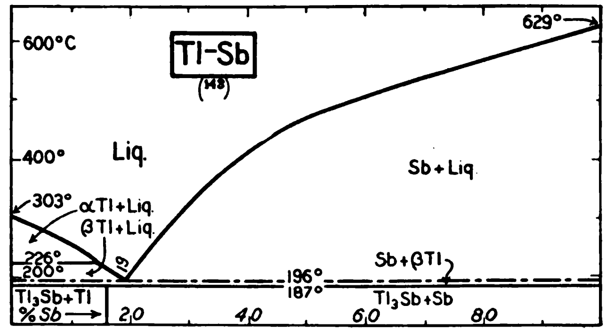

Ni-P
(68)
1450°
1400°C
1300°
1200°
1100°
1000°
900°
Ni₅P₂
1184°
β Ni₅P₂ + Liq.
(Ni₅P₂) + Liq.
Ni₂P
1112°
1110°
Ni + Liq.
α Ni₅P₂ + Liq.
1025
975
(Ni₅P₂)
Ni₃P + Liq.
880°
11
Ni + Ni₃P
%P →
10
20

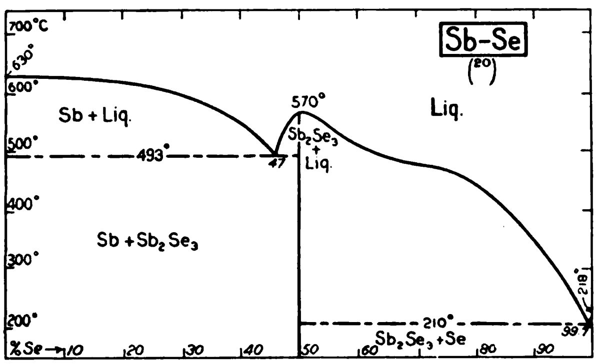

Ni-Sb
(77)
1400°C
1455°
Liq.
1200°
Ni₅Sb₂ + Liq.
1160°
NiSb + Liq.
1170°
β + Liq.
47
1072°
65
1100°
1000°
NiSb
40
Ni₅Sb₂
Ni₅Sb₂ + β
92
β-(Sb,Ni) Non-mag.
800°
NiSb + Liq.
α (Ni, NiSb)
NiSb + Ni₅Sb₂
630°
Sb + Liq.
3.2
612°
600°
Ni₅Sb₂ + Ni₄Sb
677°
Ni₄Sb + β
γ-(Sb,Ni) Mag.
330°
300°
NiSb + Sb
Ni₄Sb + γ
%Ni →
20
40
60
80

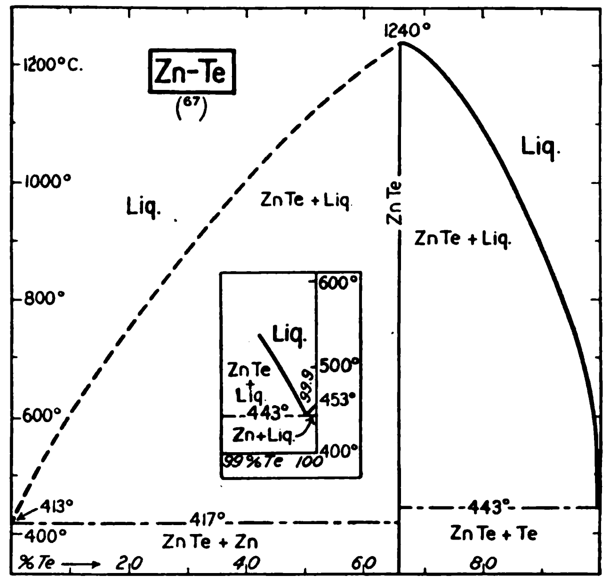

V-Ni
(40)
1450°C
Liq.
1355°
19
α + Liq.
1300°
365°
α-(V, Ni)
(Non-Magnetic)
300°
α + β
β-(V, Ni) (Magnetic)
200°
%V →
20
30

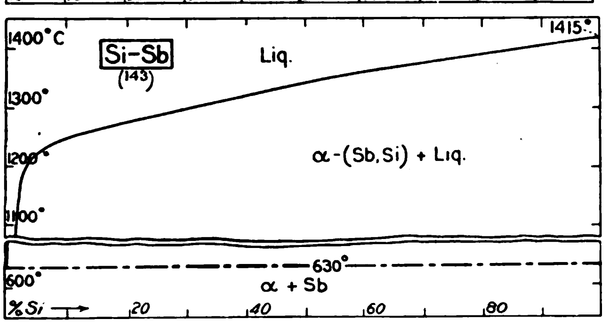

Ni-Si
(43)
1450°
1400°C
1415°
β + Liq.
1310°
α + Liq.
10
1200°
6
12
1155°
α + β
1125°
Liq.
Si + Liq.
α-(Si, Ni)
β-(Ni₂Si)
βNi₂Si₃ + Liq.
41
1020°
42
β Ni₂Si₃ + Si
1000°
1000°
27
37
24
959°
975
NiSi + βNi₂Si₃
950°
Ni₃Si
23
830°
α Ni₂Si₃ + Si
800°
β + Ni₃Si₂
Ni₃Si₂
NiSi
α Ni₂Si₃ + NiSi
Ni₂Si₃
%Si →
20
40
60
80

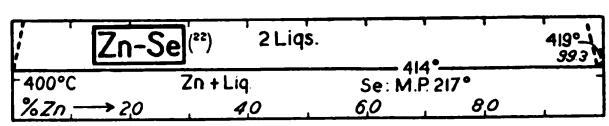

Pt-Sb
(39)
1225°
1200°C
1100°
1000°
900°
800°
700°
Pt Sb₂ + Liq.
PtSb₂+Liq.
1045°
PtSb₂
Liq.
Pt Sb + Liq.
?
747°
670°
640°
631°
Pt₅Sb₂+?
77
%Pt 20 40 60 80

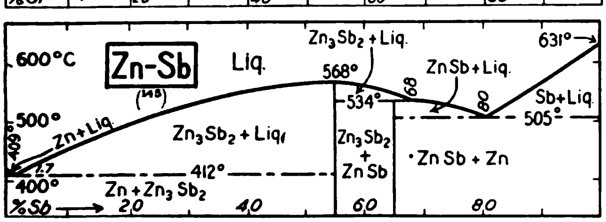

Tl-Sb
(143)
629°
600°C
400°
Liq.
Sb + Liq.
303°
αTl+Liq.
βTl+Liq.
226°
200°
19
Sb+βTl
196°
187°
Tl₃Sb+Tl
Tl₃Sb+Sb
%Sb 20 40 60 80

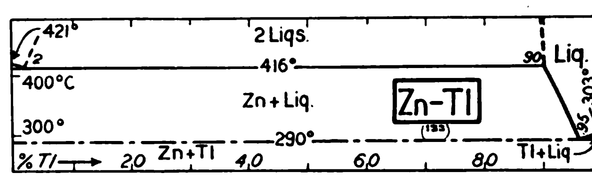

Sb-Se
(20)
700°C
630°
600°
500°
400°
300°
200°
570°
Sb + Liq.
Liq.
Sb₂Se₃ + Liq.
493°
47
Sb + Sb₂ Se₃
218°
210°
Sb₂Se₃+Se
99.7
%Se 10 20 30 40 50 60 70 80 90

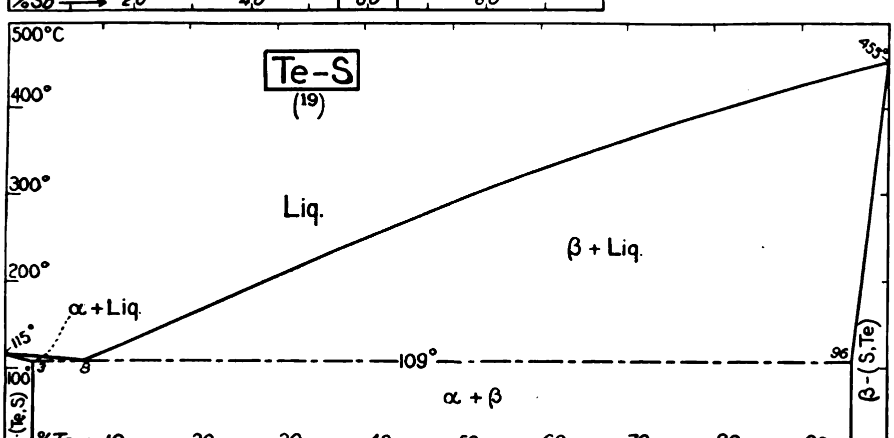

Zn-Te
(67)
1240°
1200°C.
1000°
800°
600°
Liq.
Zn Te + Liq.
ZnTe
Zn Te + Liq.
Liq.
600°
Liq.
Zn Te + Liq.
99.9
500°
453°
443°
Zn+Liq.
400°
99 %Te 100
413°
400°
417°
Zn Te + Zn
443°
Zn Te + Te
%Te 20 40 60 80

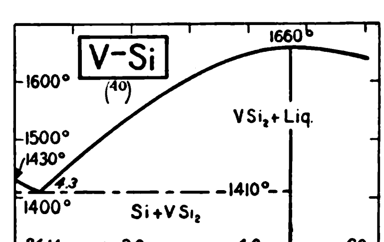

Si-Sb
(143)
1415°
1400°C
1300°
1200°
1100°
Liq.
α-(Sb,Si) + Liq.
630°
600°
α + Sb
%Si 20 40 60 80

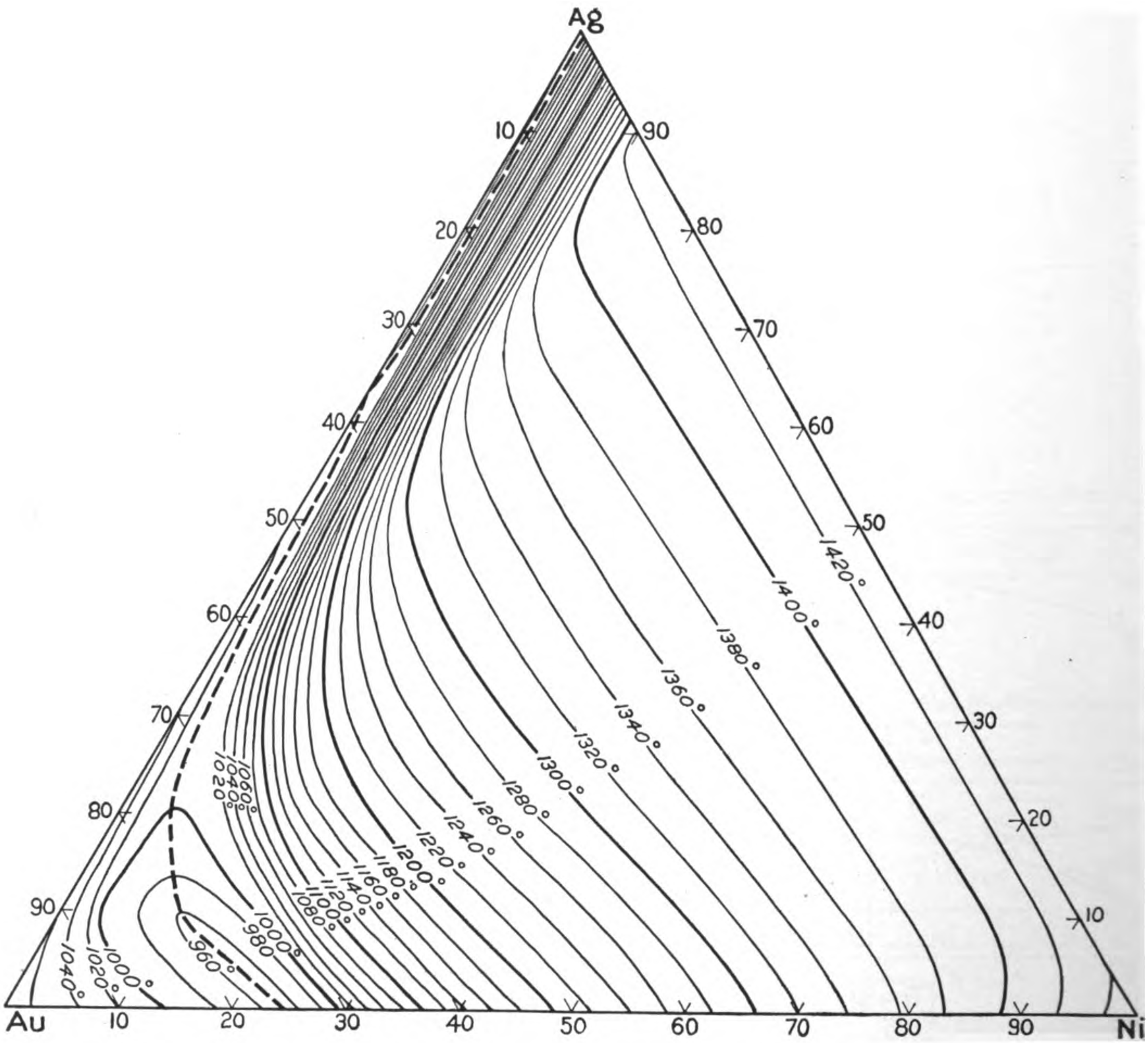

Zn-Se
(22)
2 Liqs.
419°
99.3
414°
400°C
Zn + Liq.
Se: M.P. 217°
%Zn 20 40 60 80


Zn-Sb
(143)
600°C
Liq.
Zn₃Sb₂ + Liq.
631°
568°
ZnSb+Liq.
534°
68
80
Sb+Liq.
505°
500°
409°
Zn+Liq.
Zn₃Sb₂ + Liq.
Zn₃Sb₂ + ZnSb
Zn Sb + Zn
2.7
412°
400°
Zn + Zn₃ Sb₂
%Sb 20 40 60 80

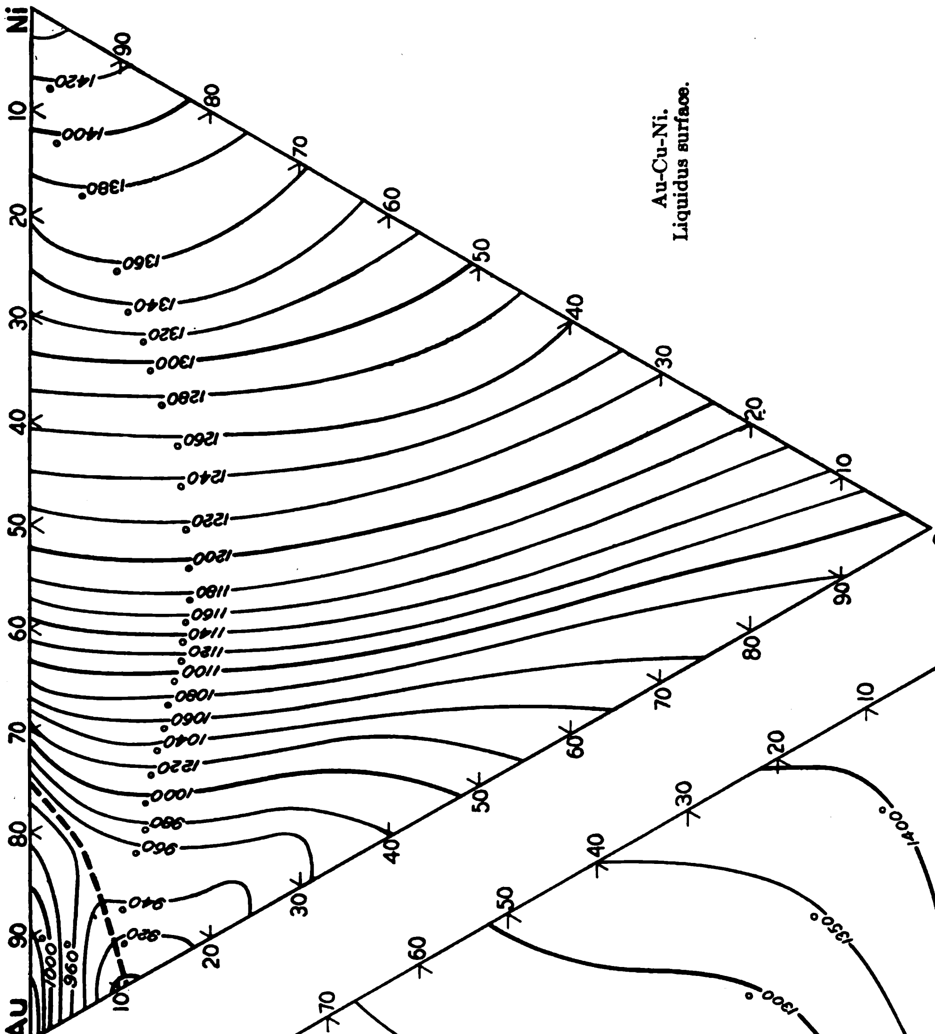

421°
1.2
2 Liqs.
416°
90
Liq.
400°C
Zn + Liq.
Zn-Tl
(123)
303°
300°
290°
95
Zn+Tl
Tl+Liq.
%Tl 20 40 60 80


Te-S
(19)
500°C
452°
400°
300°
Liq.
β + Liq.
200°
α + Liq.
115°
3
8
109°
96
100
α + β
α-(Te,S)
β-(S,Te)
%Te 10 20 30 40 50 60 70 80 90

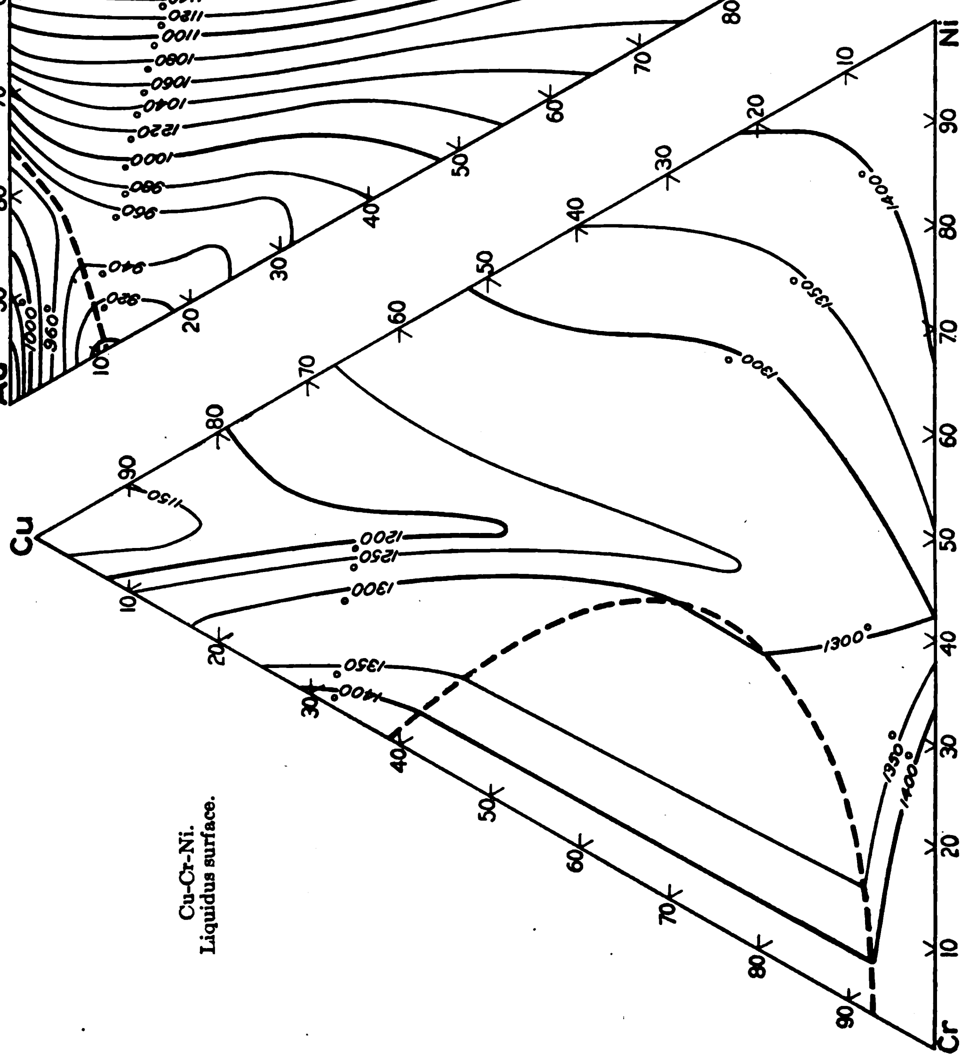

V-Si
(40)
1660°
1600°
VSi₂ + Liq.
1500°
1430°
4.3
1410°
1400°
Si + VSi₂
%V 20 40 60



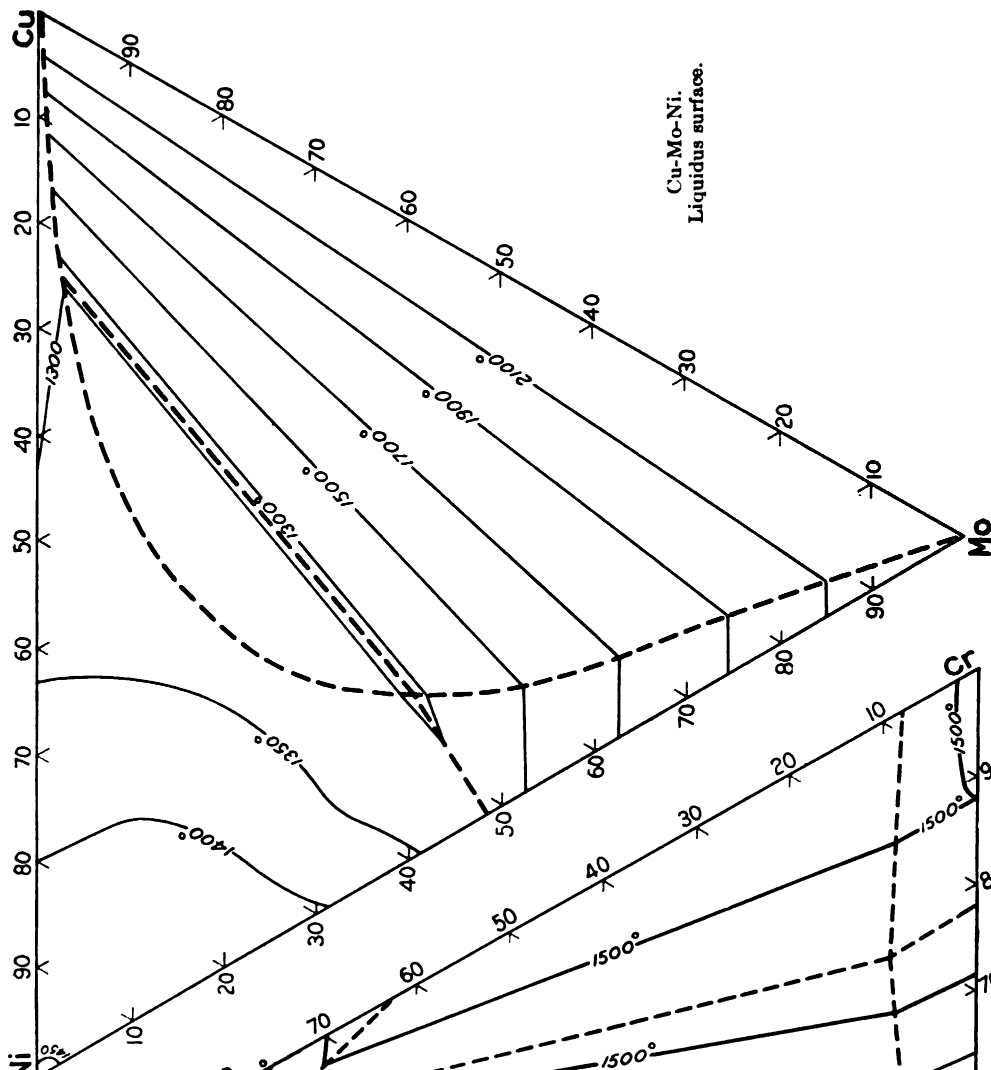
Ag-Au-Ni. Liquidus surface.



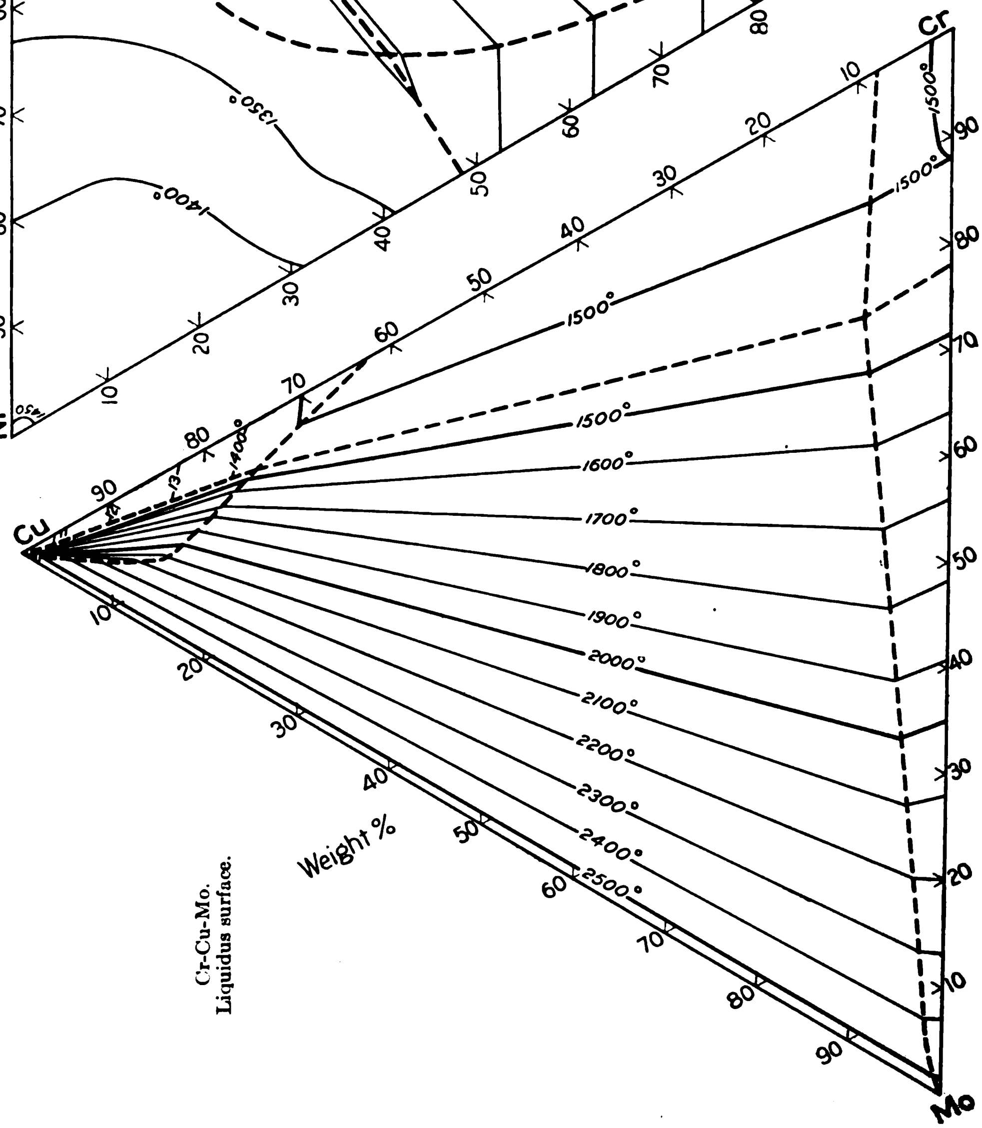
Au-Cu-Ni.
Liquidus surface.



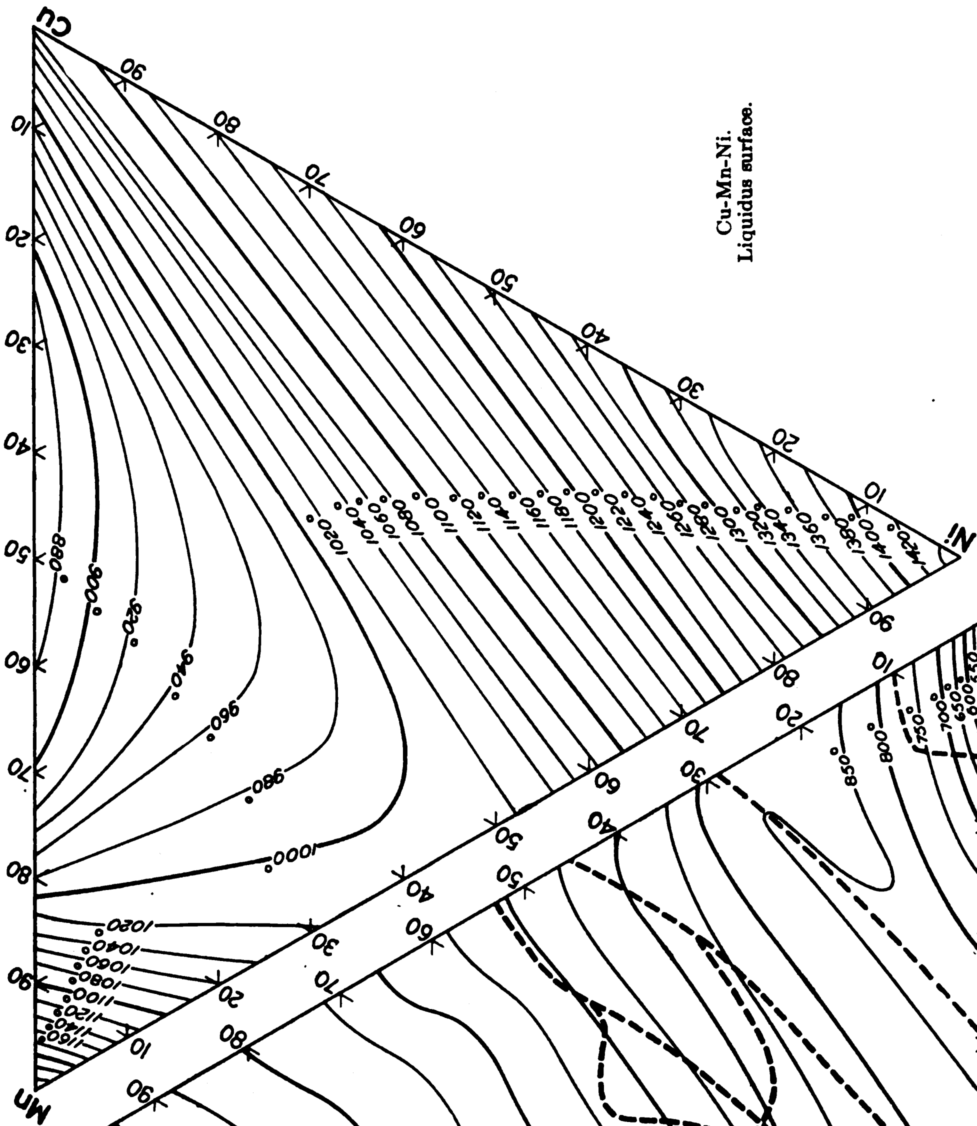
Cu-Cr-Ni.
Liquidus surface.



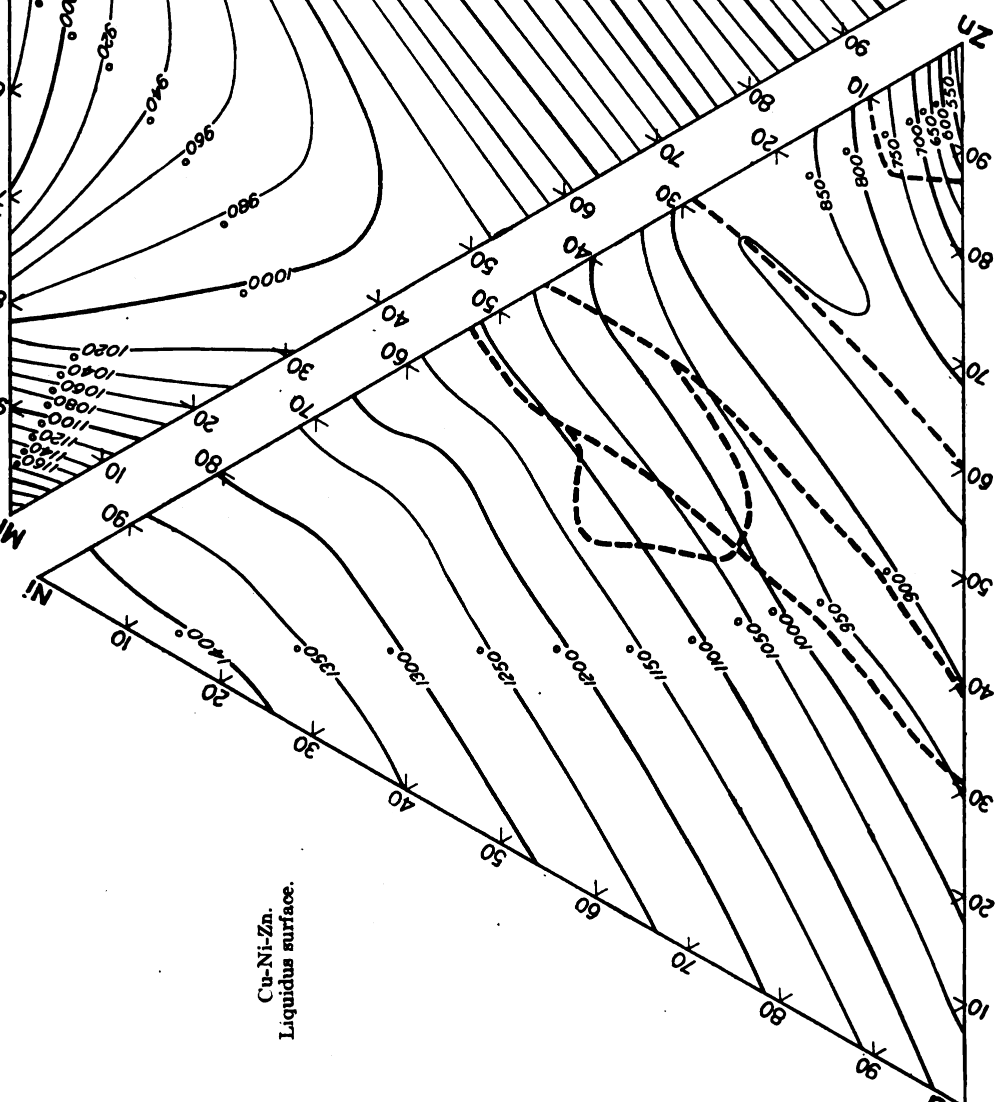
Cu-Mo-Ni.
Liquidus surface.



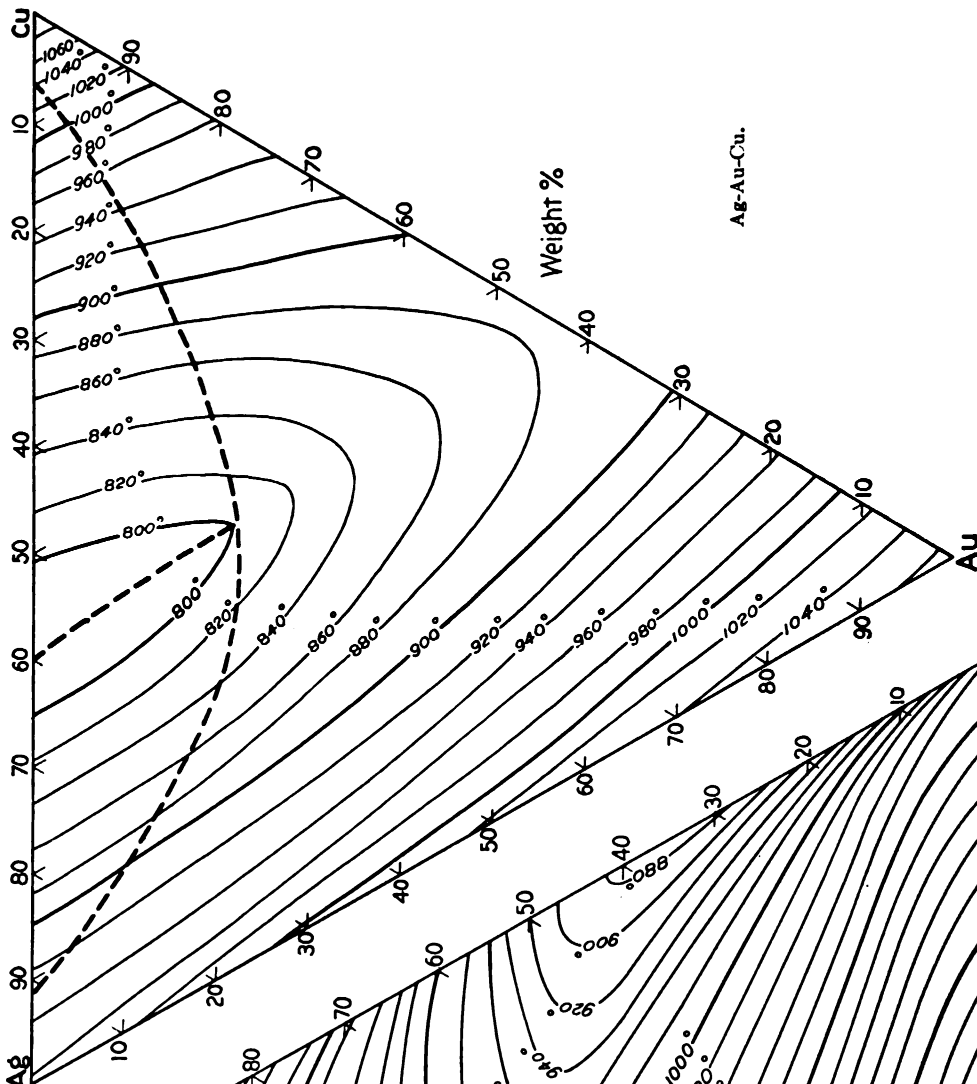
Cr-Cu-Mo.
Liquidus surface.



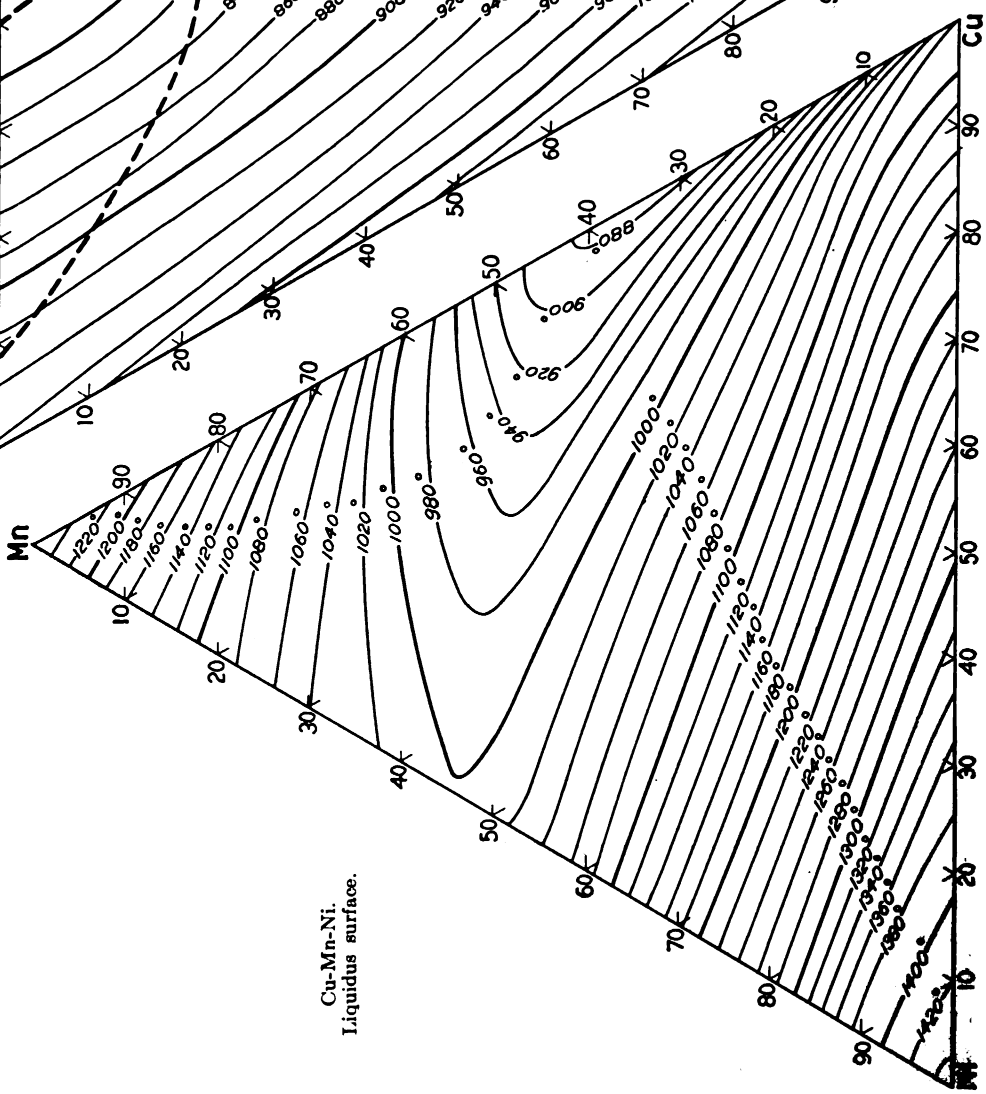
Cu-Mn-Ni.
Liquidus surface.



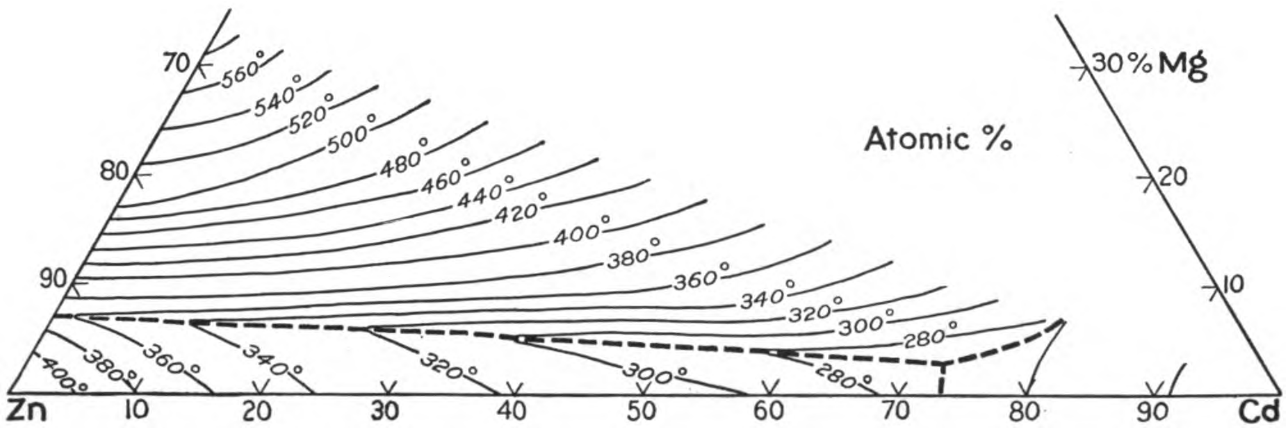
Cu-Ni-Zn.
Liquidus surface.



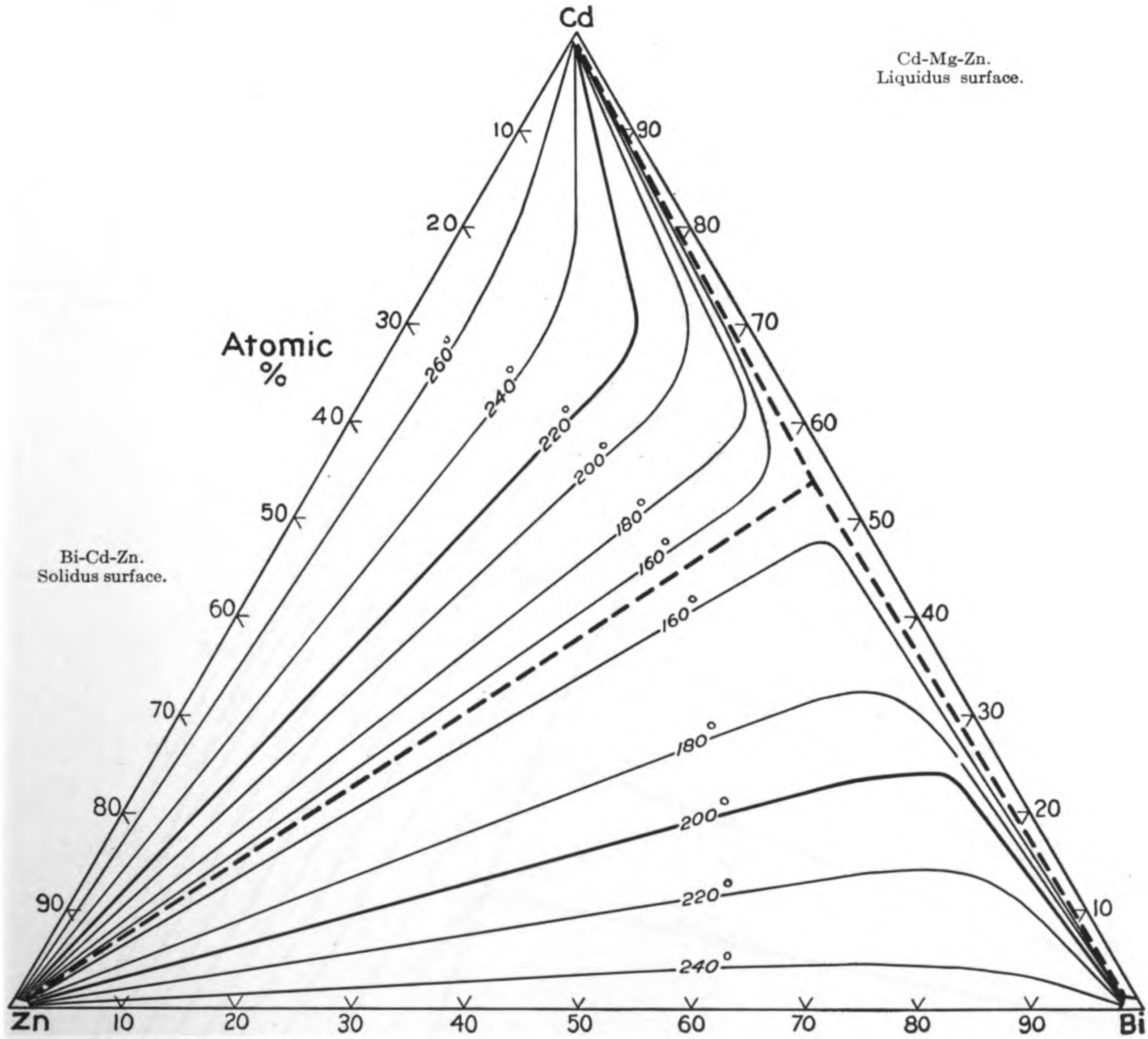
Ag-Au-Cu.



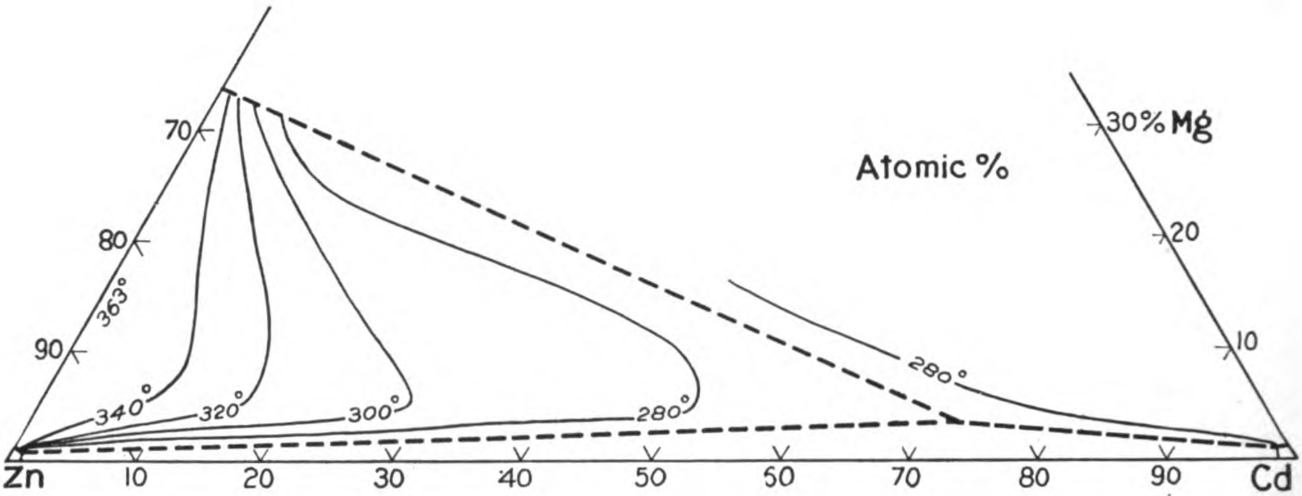
Cu-Mn-Ni.
Liquidus surface.



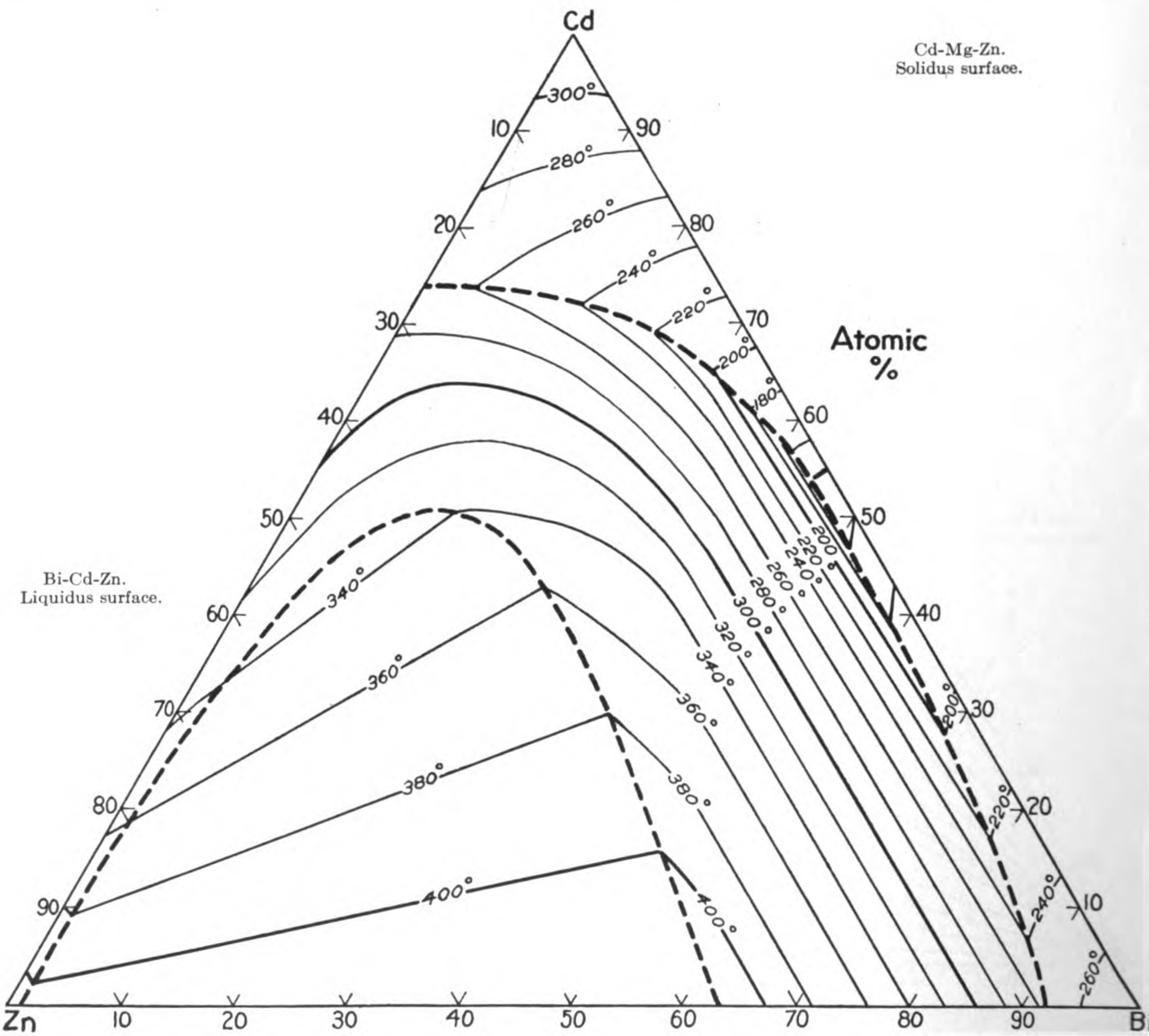
Cd-Mg-Zn.
Liquidus surface.



Bi-Cd-Zn.
Solidus surface.



Cd-Mg-Zn.
Solidus surface.



Bi-Cd-Zn.
Liquidus surface.

FERROUS ALLOYS

C. H. Desch

INDEX OF SYSTEMS

* Two immiscible liquid phases.

LITERATURE

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(1) Banberger, Einerl and Nussbaum, *77*, **45**: 141; 25. (2) Benedicks, *55*, **7**: 290; 11. (3) Bureau of Standards, Washington, D. C., *O.* (4) Carpenter and Keeling, *140*, **65**: 224; 04. (5) Chiyevskii and Herdt, *431*, **I**: 353; 15. *430*, **98**: 396; 16. (6) Chiyevskii and Schulgin, *140*, **95**: 189; 17. (7) Denecke, *93*, **154**: 180; 26. (8) Desch, *O.* (9) Friedrich, *192*, **4**: 129; 07.

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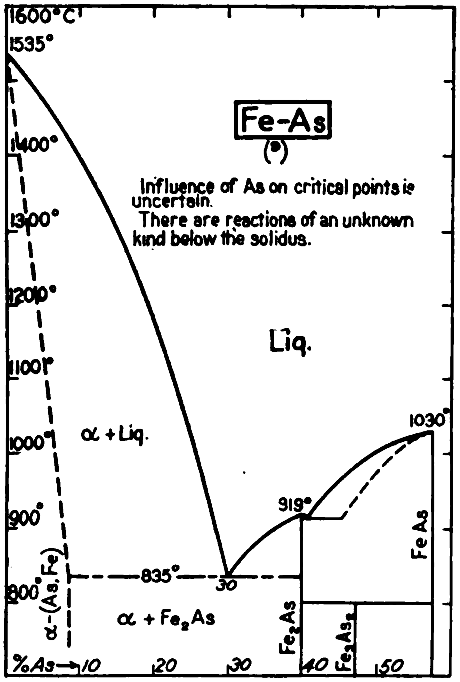
(20) Honda and Murakami, *159*, **12**: 1; 24. (21) Isaac and Tammann, *93*, **53**: 281; 07. (22) Isaac and Tammann, *93*, **55**: 58; 07. (23) Kase, *159*, **14**: 173; 25. (24) Konstantinov, *93*, **66**: 209; 09. (25) Kurnakov and Konstantinov, *93*, **58**: 1; 08. (26) Lamort, *139*, **11**: 225; 14. (27) van Liempt, *70*, **45**: 203; 26. (28) Loebe and Becker, *93*, **77**: 301; 12. (28.1) Meierling and Denecke, *93*, **151**: 113; 26. (29) Murakami, *159*, **7**: 217; 18.

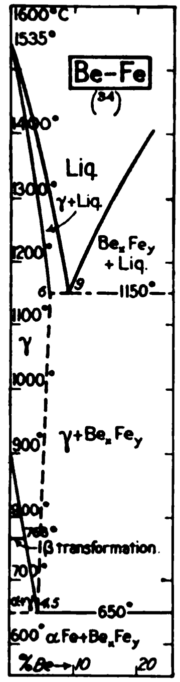
(30) Murakami, *159*, **10**: 79; 21. (31) National Physical Laboratory, England, *O.* (32) Oberhoffer, *77*, **44**: 979; 24. (33) Oberhoffer, Daeves and Rapatz, *77*, **44**: 432; 24. (34) Oesterheld, *93*, **97**: 36; 16. (35) Osmond, *74*, **2**: 798; 05. (36) Ozawa, *159*, **11**: 333; 22. (37) Pakulla and Oberhoffer, *Ver. deutscher Eisenhüttenleute, Werkstoffausschuss*, No. **68**; 1925. (38) Parravano, *36*, **42 II**: 367; 12. *95*, **4**: 171; 13. (39) Petrenko, *93*, **53**: 212; 07.

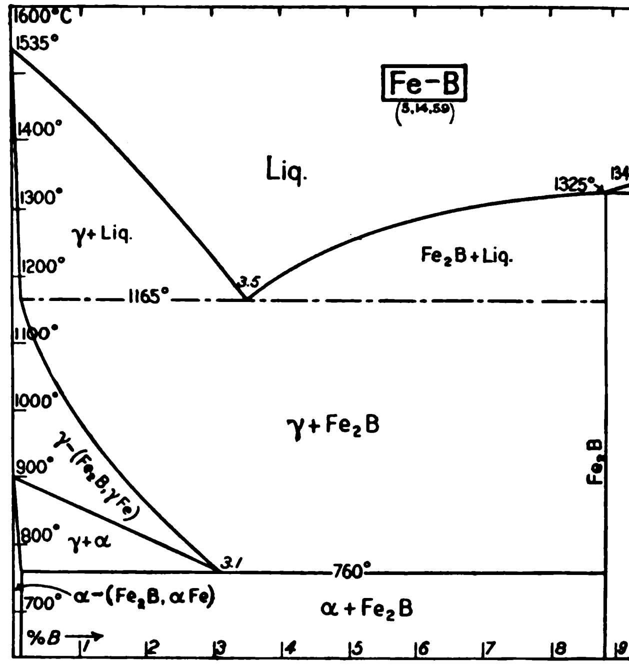
(40) Phragmén, *220*, **1923**: 121. (40.1) Phragmén, *115*, **122**: 370; 26. (41) Portevin, *74*, **6**: 1264; 09. (42) Raydt and Tammann, *93*, **83**: 257; 13. (43) Rümelin and Fick, *139*, **12**: 41; 15. (44) Rümelin and Maire, *139*, **12**: 141; 15. (45) Ruer and Biren, *93*, **113**: 98; 20. (46) Ruer and Kaneko, *139*, **11**: 33; 13. (47) Ruer and Klesper, *139*, **11**: 257; 14. (48) Russell, *140*, **104**: 247; 21. (49) Saklatwalla, *140*, **77**: 92; 08.

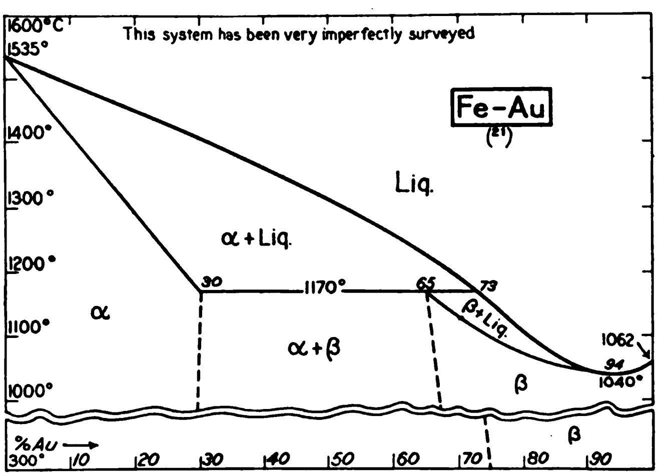
(50) Schönert, *93*, **154**: 224; 26. (51) Stead, *140*, **91**: 140; 15. (52) Stead, *140*, **97**: 389; 18. (53) Tamaru, *159*, **14**: 25; 25. (54) Tritton and Hanson, *140*, **110**: 90; 24. (55) von Vegesack, *93*, **52**: 30; 07. (56) von Vegesack, *93*, **154**: 30; 26. (57) Vogel, *93*, **99**: 25; 17. (58) Vogel and Tammann, *93*, **58**: 73; 08. (59) Vogel and Tammann, *93*, **123**: 225; 22.

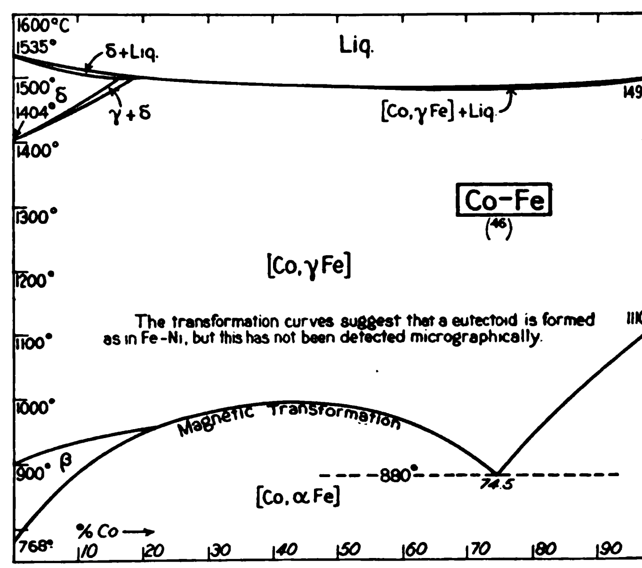
(60) Wever and Reinecken, *226*, **7**: 21; 25.

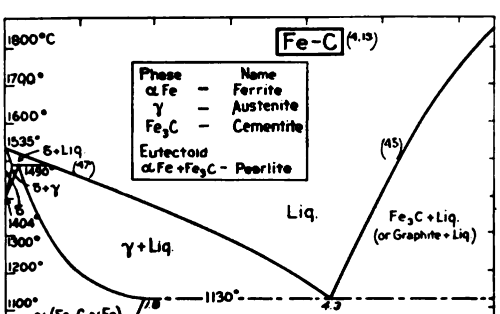

Fe-As
(8)
Influence of As on critical points is uncertain.
There are reactions of an unknown kind below the solidus.
Liq.
α + Liq.
α + Fe2As
α-(As, Fe)
Fe2As
Fe3As2
FeAs
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
900°
800°
919°
1030°
835°
30
%As→ 10 20 30 40 50


Be-Fe
(34)
Liq.
γ+Liq.
BexFey + Liq.
γ
γ+BexFey
β transformation.
α Fe+BexFey
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
900°
800°
768°
700°
600°
1150°
650°
%Be→ 10 20

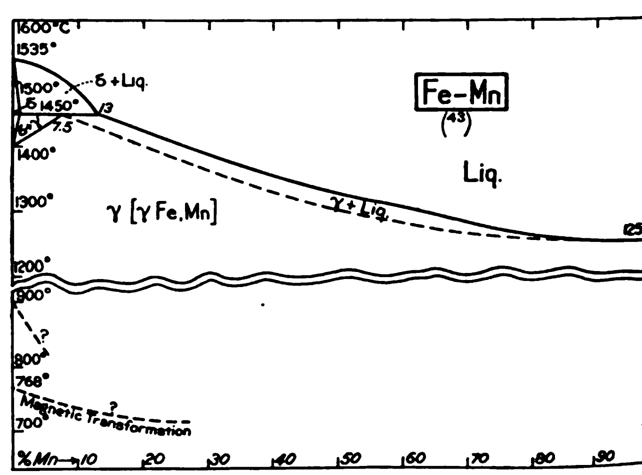

Fe-B
(5,14,59)
Liq.
γ+ Liq.
Fe2B+Liq.
γ+Fe2B
γ-(Fe2B, γFe)
γ+α
α-(Fe2B, αFe)
α+Fe2B
Fe2B
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
900°
800°
700°
1325°
1345°
1165°
760°
3.5
3.1
%B→ 1 2 3 4 5 6 7 8 9

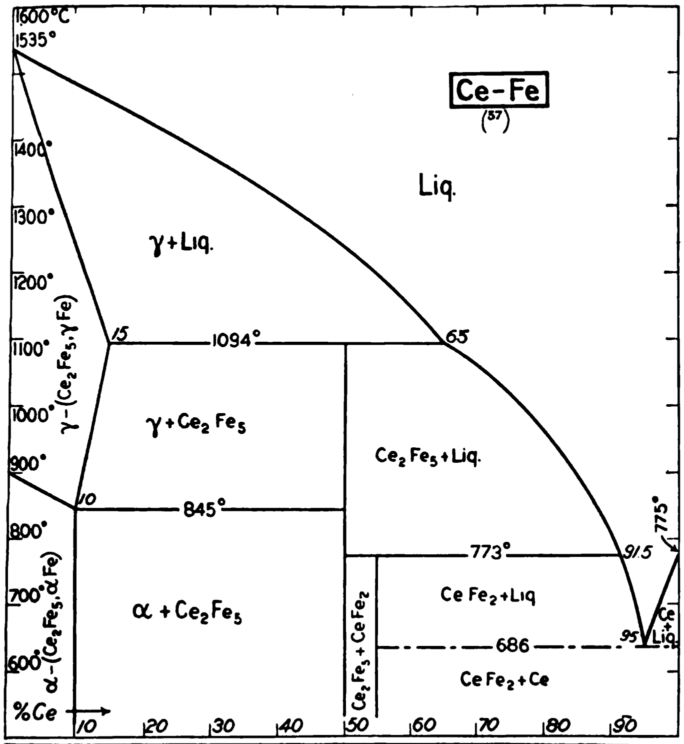

This system has been very imperfectly surveyed
Fe-Au
(21)
Liq.
α+Liq.
α
α+β
β+Liq.
β
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
1170°
30
65
73
94
1062
1040°
%Au→
300° 10 20 30 40 50 60 70 80 90

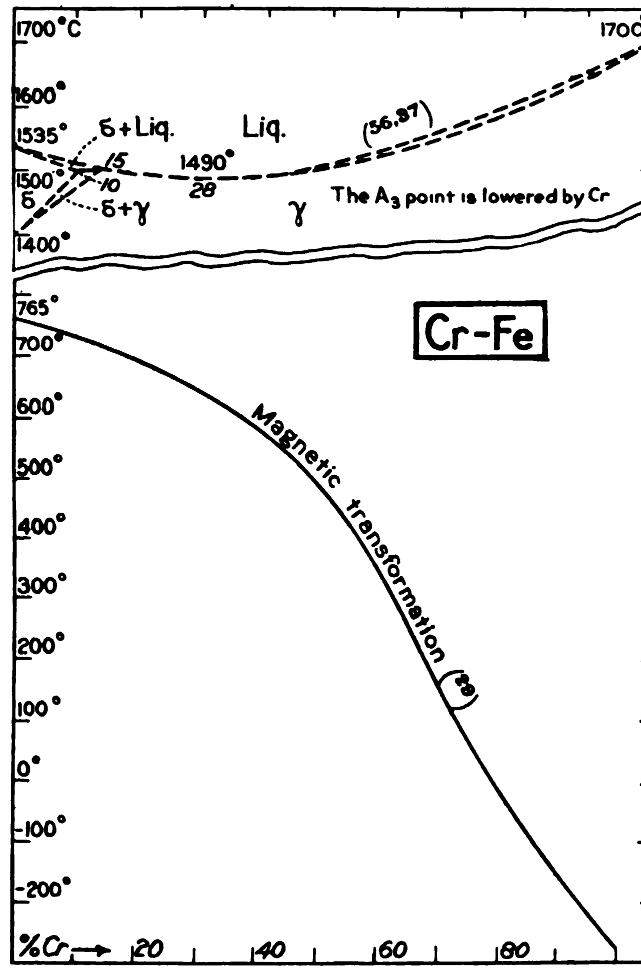

δ+Liq.
Liq.
δ
γ+δ
[Co, γFe] + Liq.
Co-Fe
(46)
[Co, γFe]
The transformation curves suggest that a eutectoid is formed as in Fe-Ni, but this has not been detected micrographically.
Magnetic Transformation
β
[Co, α Fe]
1600°C
1535°
1500°
1404°
1400°
1300°
1200°
1100°
1000°
900°
768°
1495
1110°
880°
74.5
% Co→ 10 20 30 40 50 60 70 80 90

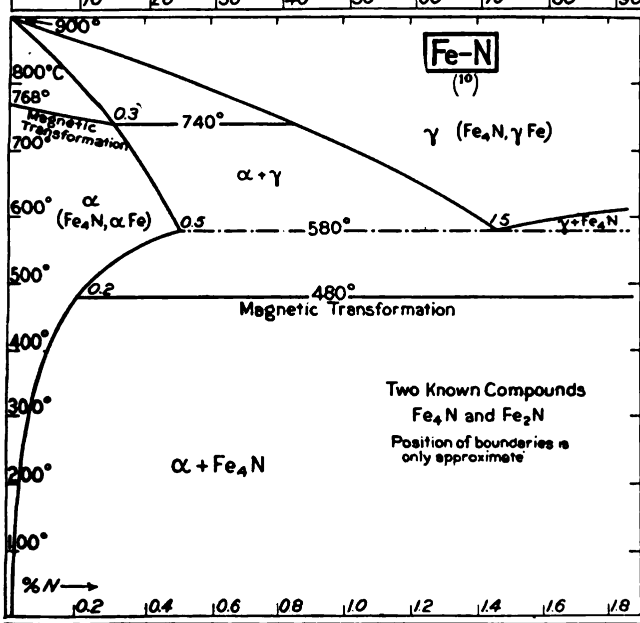

Fe-C (4,13)
Phase Name
α Fe - Ferrite
γ - Austenite
Fe3C - Cementite
Eutectoid
α Fe + Fe3C - Pearlite
δ+Liq.
δ+γ
δ
Liq.
γ+Liq.
Fe3C+Liq. (or Graphite + Liq.)
(45)
(47)
γ (Fe3C, γFe)
α Fe + γ
γ + Fe3C
(4)
Temperatures revised by comparison with (8,31)
Magnetic transformation of α Fe
α Fe + Fe3C
Magnetic transformation of Fe3C at 215°
1800°C
1700°
1600°
1535°
1500°
1400°
1300°
1200°
1100°
1000°
900°
800°
700°
600°
1130°
768°
700°
1.8
4.3
0.9
%C→ 1 2 3 4 5 6

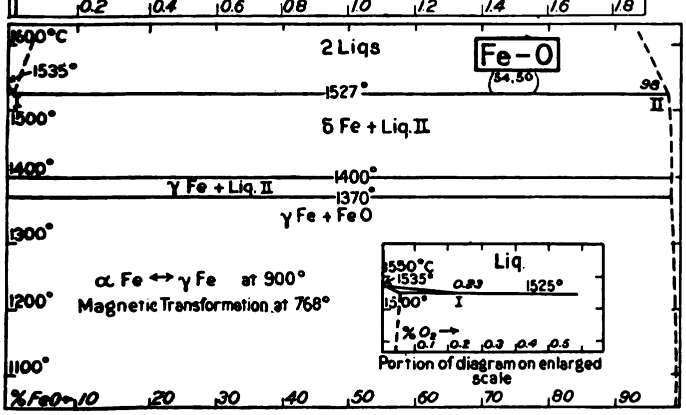
See p. 609

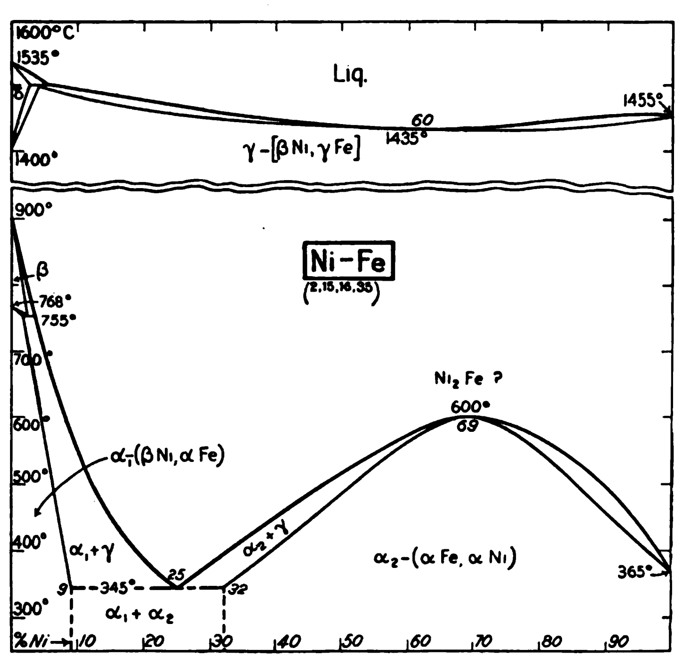

δ+Liq.
Fe-Mn
(43)
Liq.
γ+Liq.
γ [γ Fe, Mn]
Magnetic Transformation
1600°C
1535°
1500°
1450°
1400°
1300°
1200°
900°
800°
768°
700°
13
7.5
1250°
%Mn→ 10 20 30 40 50 60 70 80 90



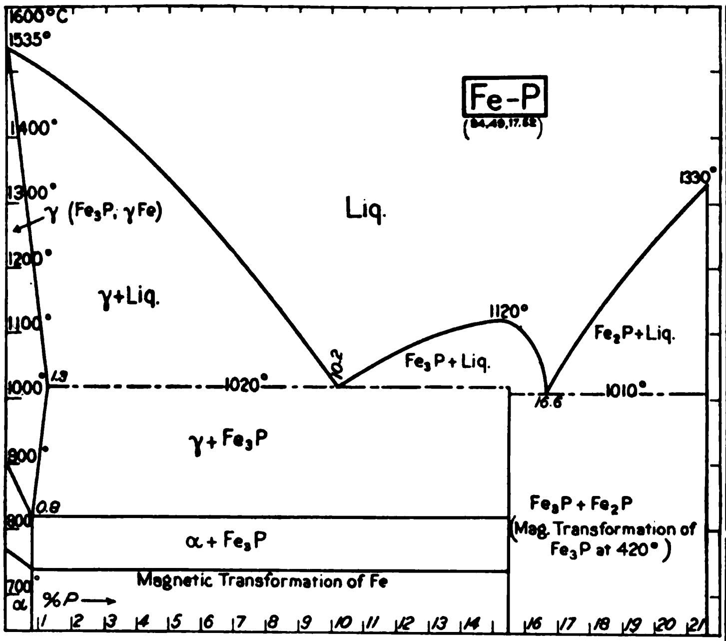


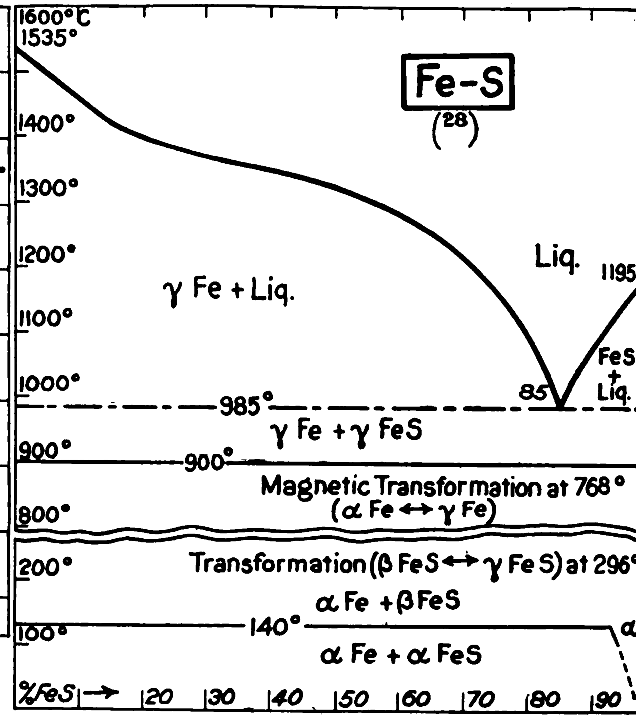


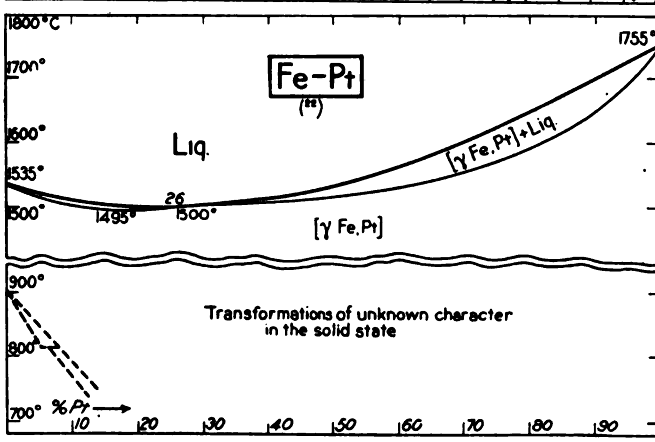


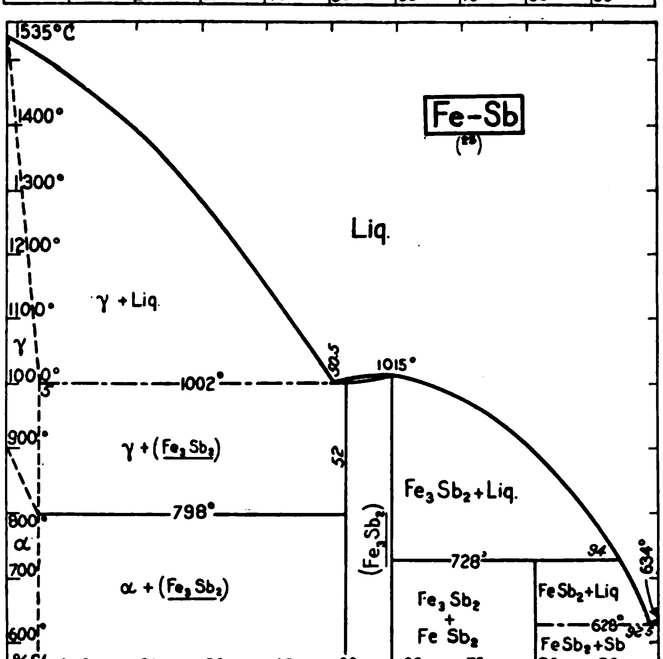


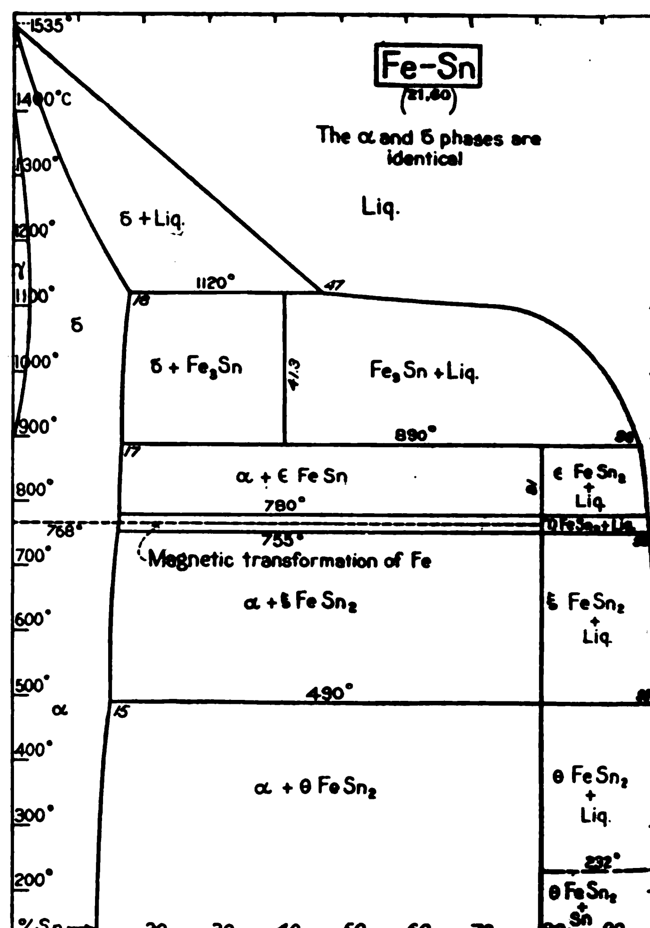
Digitized by Google

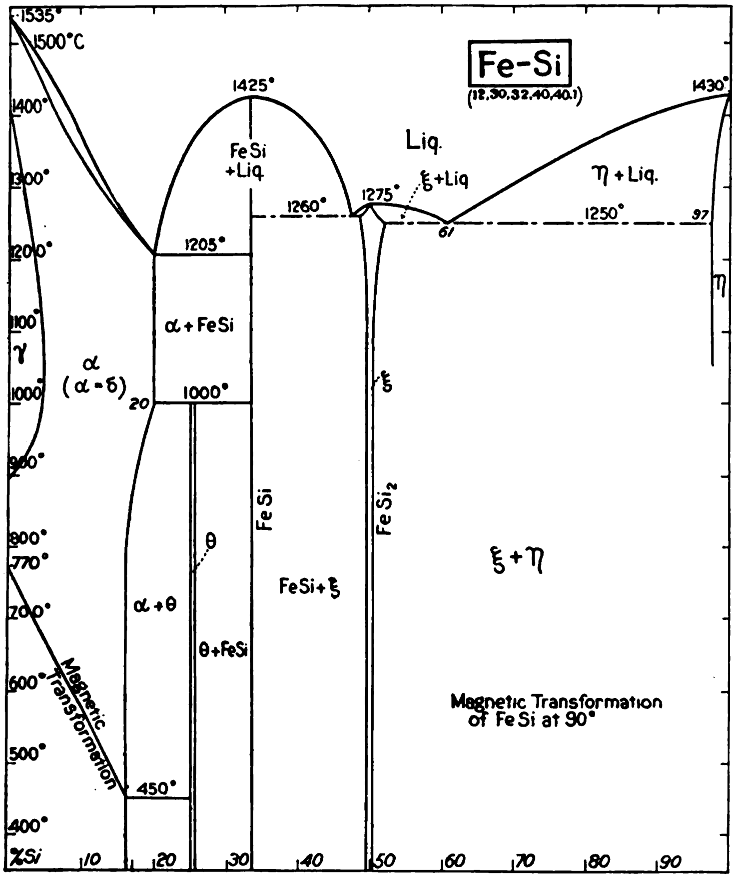

Fe-P
1600°C
1535°
1400°
1300°
γ (Fe3P; γFe)
1200°
1100°
1000°
900°
800°
700°
α
Liq.
γ+Liq.
1120°
1330°
Fe3P + Liq.
Fe2P+Liq.
1020°
1010°
10.2
16.6
γ+ Fe3P
Fe3P + Fe2P
(Mag. Transformation of Fe3P at 420°)
α + Fe3P
Magnetic Transformation of Fe
%P

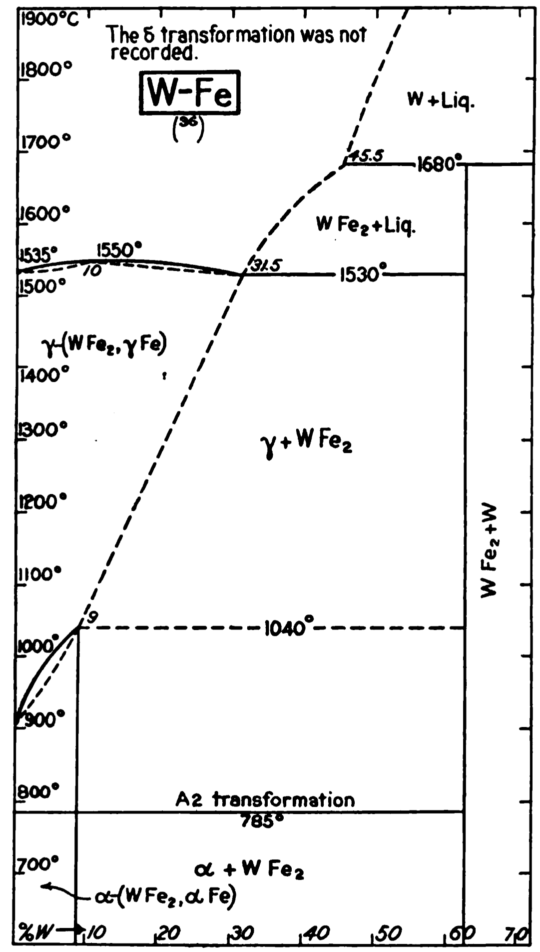

Fe-S
(28)
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
900°
800°
200°
100°
Liq.
1195°
γ Fe + Liq.
FeS + Liq.
85
985°
γ Fe + γ FeS
900°
Magnetic Transformation at 768°
(α Fe ↔ γ Fe)
Transformation (β FeS ↔ γ FeS) at 296°
α Fe + β FeS
140°
α?
α Fe + α FeS
%FeS
20 30 40 50 60 70 80 90

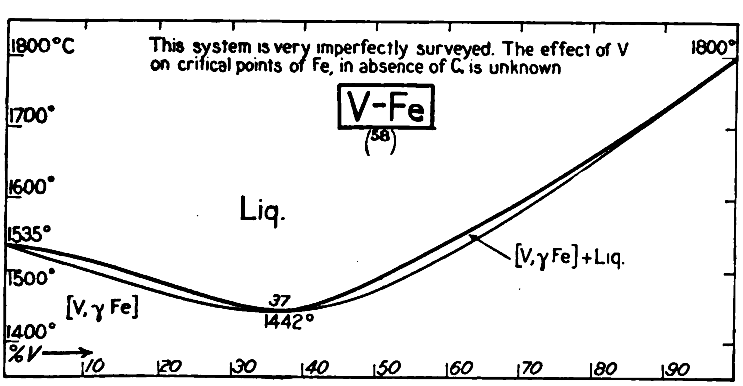

Fe-Pt
1800°C
1755°
1700°
1600°
1535°
1500°
Liq.
[γ Fe, Pt]+Liq.
26
1495°
1500°
[γ Fe, Pt]
900°
800°
700°
Transformations of unknown character in the solid state
%Pt
10 20 30 40 50 60 70 80 90

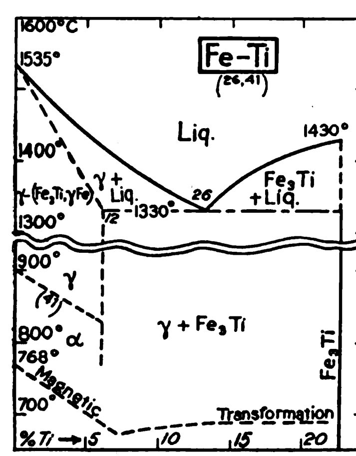

Fe-Sb
1535°C
1400°
1300°
1200°
1100°
1000°
900°
800°
700°
600°
γ
α
Liq.
γ + Liq.
1015°
1002°
γ + (Fe3Sb2)
798°
(Fe3Sb2)
Fe3Sb2+Liq.
728°
634°
α + (Fe3Sb2)
Fe3Sb2 + Fe Sb2
FeSb2+Liq
628°
FeSb2+Sb
%Sb
10 20 30 40 50 60 70 80 90

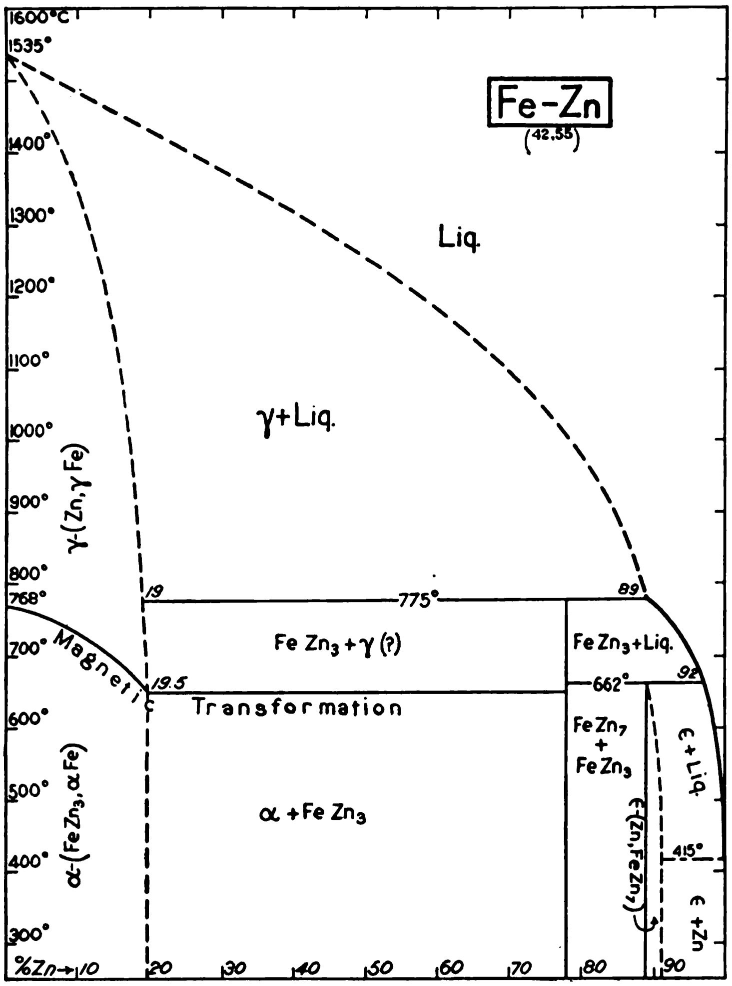

Fe-Sn
The α and δ phases are identical
1535°
1400°C
1300°
1200°
1100°
1000°
900°
800°
700°
600°
500°
400°
300°
200°
γ
δ
α
Liq.
δ + Liq.
1120°
δ + Fe3Sn
Fe3Sn + Liq.
890°
α + ϵ FeSn
ϵ FeSn2 + Liq.
780°
768°
755°
Magnetic transformation of Fe
α + ξ FeSn2
ξ FeSn2 + Liq.
490°
α + θ FeSn2
θ FeSn2 + Liq.
232°
θ FeSn2 + Sn
%Sn
20 30 40 50 60 70 80 90

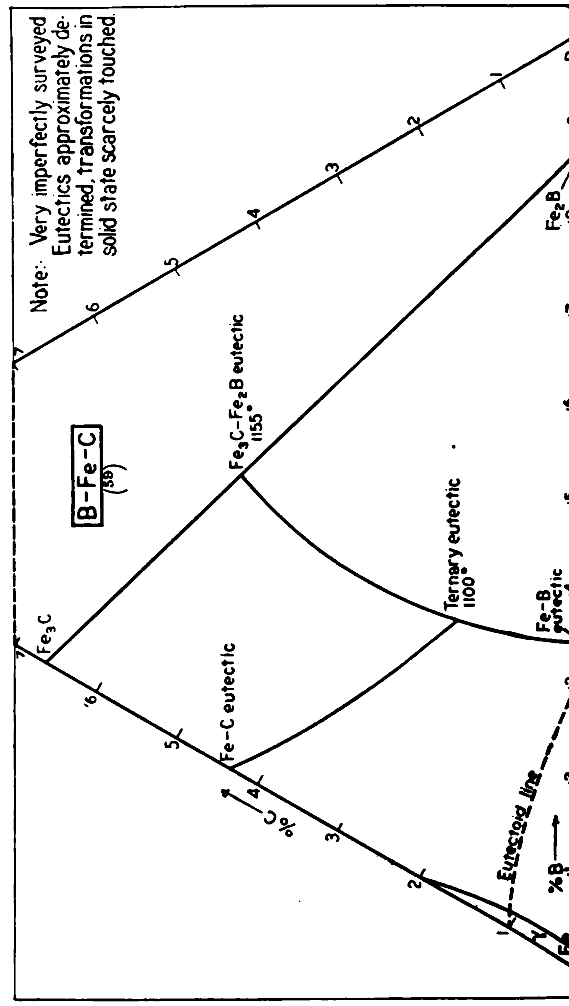

Fe-Si
(12,30,32,40,40.1)
1535°
1500°C
1425°
1430°
Liq.
FeSi
+Liq.
ξ+Liq
η + Liq.
1260°
1275°
1250°
97
61
1205°
α + FeSi
α
(α = δ)
γ
20
1000°
η
ξ
FeSi
FeSi$_2$
θ
ξ + η
FeSi+ξ
α + θ
θ+FeSi
770°
Magnetic Transformation
Magnetic Transformation of FeSi at 90°
450°
%Si

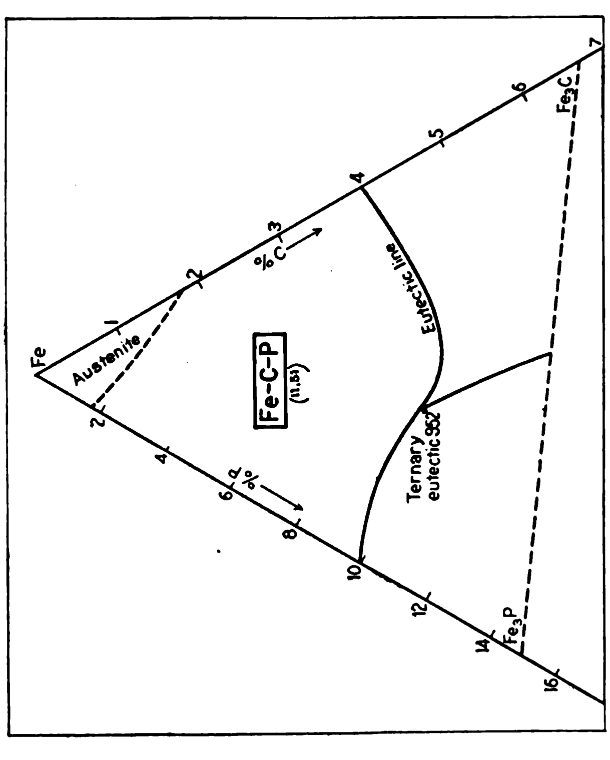

1900°C
The δ transformation was not recorded.
W-Fe
(36)
W + Liq.
45.5
1680°
W Fe$_2$+Liq.
1535°
1550°
10
31.5
1530°
γ-(W Fe$_2$, γ Fe)
γ + W Fe$_2$
W Fe$_2$+W
9
1040°
A2 transformation
785°
α + W Fe$_2$
α-(W Fe$_2$, α Fe)
%W

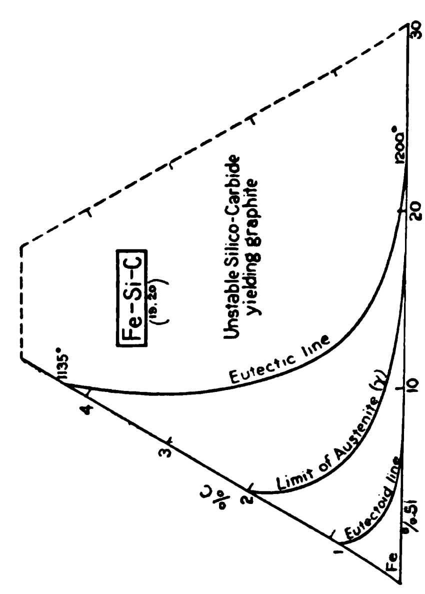

1800°C
This system is very imperfectly surveyed. The effect of V on critical points of Fe, in absence of C, is unknown
1800°
V-Fe
(58)
Liq.
1535°
[V, γ Fe]+Liq.
[V, γ Fe]
37
1442°
%V

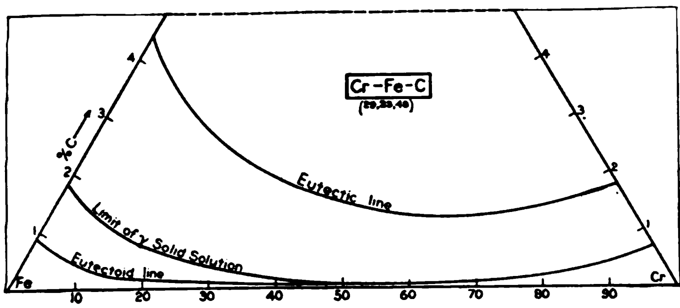

1600°C
Fe-Ti
(26,41)
1535°
Liq.
1430°
γ + Liq.
Fe$_3$Ti
+Liq.
γ-(Fe$_3$Ti, γFe)
26
7.2
1330°
γ
(4)
α
γ + Fe$_3$Ti
Fe$_3$Ti
768°
Magnetic
Transformation
%Ti

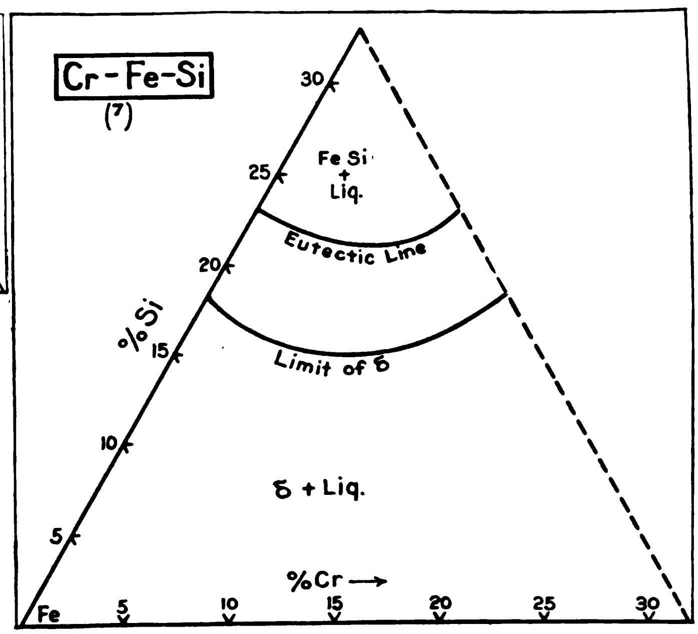

Fe-Zn
(42,55)
1600°C
1535°
1400°
1300°
1200°
1100°
1000°
900°
800°
768°
700°
600°
500°
400°
300°
Liq.
γ+Liq.
γ-(Zn, γ Fe)
Magnetic
19
775°
89
Fe Zn₃ + γ (?)
Fe Zn₃+Liq.
19.5
Transformation
662°
92
Fe Zn₇ + Fe Zn₃
ε + Liq.
α + Fe Zn₃
α-(Fe Zn₃, α Fe)
ε-(Zn, Fe Zn₇)
415°
ε + Zn
%Zn→10
20
30
40
50
60
70
80
90

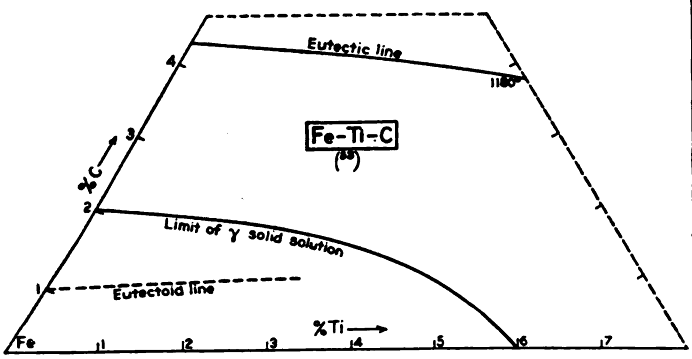

Note: Very imperfectly surveyed. Eutectics approximately determined, transformations in solid state scarcely touched.
B-Fe-C
(39)
Fe₃C-Fe₂B eutectic 1155°
Ternary eutectic 1100°
Fe-B eutectic
Fe₂B
Fe₃C
Fe-C eutectic
C %
Eutectoid line
% B
B

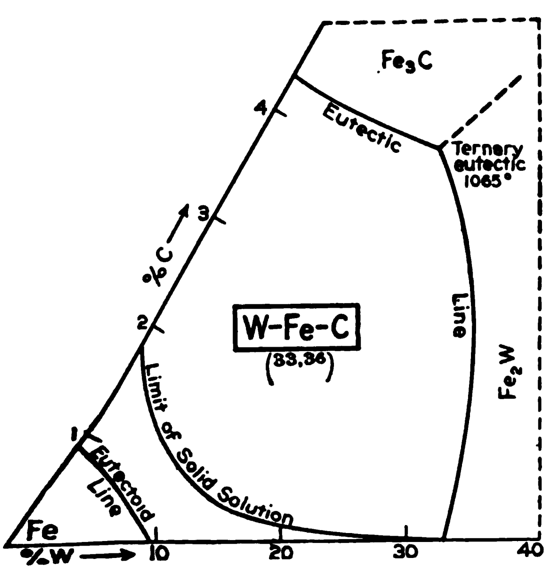

Fe-C-P
(11,51)
Fe
Austenite
% C
Eutectic line
Fe₃C
Ternary eutectic 952°
% P
Fe₃P

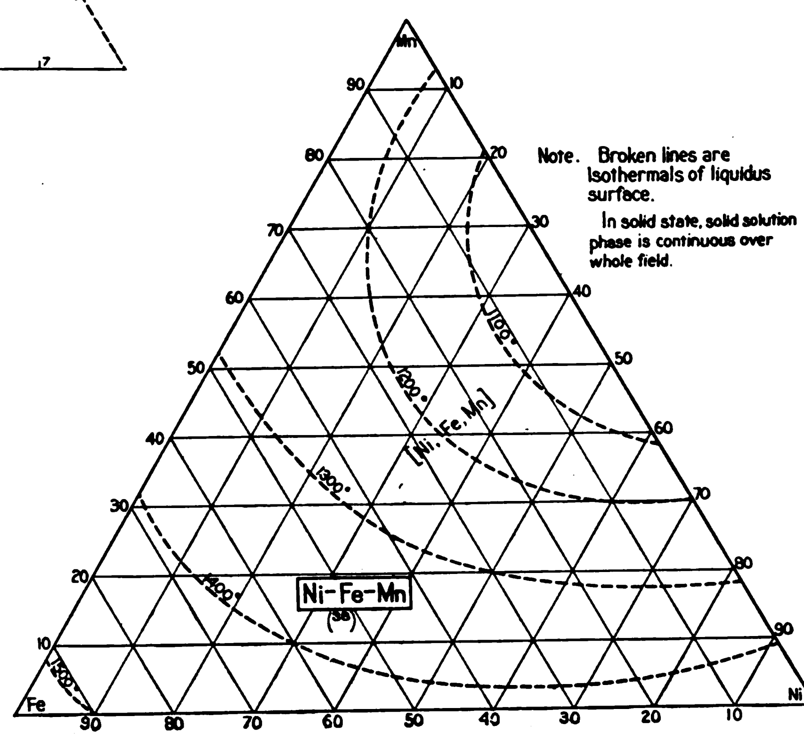

Fe-Si-C
(19,20)
Unstable Silico-Carbide yielding graphite
1200°
1135°
Eutectic line
Limit of Austenite (γ)
Eutectoid line
C %
% Si
Fe
30
20
10


Cr-Fe-C
%C
Eutectic line
Limit of γ Solid Solution
Eutectoid line
Fe
Cr
10 20 30 40 50 60 70 80 90


Cr-Fe-Si
(7)
Fe Si + Liq.
Eutectic Line
Limit of δ
δ + Liq.
%Si
%Cr
Fe
5 10 15 20 25 30


Fe-Ti-C
Eutectic line
1180°
%C
Limit of γ solid solution
Eutectoid line
%Ti
Fe


Fe₃C
Eutectic
Ternary eutectic 1065°
%C
W-Fe-C
(33,36)
Line
Fe₂W
Limit of Solid Solution
Eutectoid Line
Fe
%W
10 20 30 40


Mn
Note. Broken lines are Isothermals of liquidus surface.
In solid state, solid solution phase is continuous over whole field.
1100°
1200°
[Ni, Fe, Mn]
1300°
1400°
1500°
Ni-Fe-Mn
(36)
Fe
Ni
90 80 70 60 50 40 30 20 10

DENSITY OF THE METALLIC ELEMENTS

S. L. Archbutt (SLA); C. Benedicks (CB); C. H. Desch (CHD); D. Hanson (DH); O. F. Hudson (OFH); C. H. M. Jenkins (CHMJ); P. D. Merica (PDM); A. Portevin (AP); Thomas K. Rose (TKR); V. H. Stott (VHS)

For values of density deduced from X-ray diffraction data, *v.* vol. I, p. 340

Part I.—Solid Metals

Metal	Condition	Temp., °C	d_4^t	Lit.	Coop. exp.
Ag*	Cast or cast and compressed	0	10.50	(1, 54, 55, 59, 65, 86, 93)	TKR
	Electrolytic	25	10.49_{14}	(94)	
	Cast, compressed and heated to redness *in vacuo*	0	10.55	(93)	
	Drawn, annealed	20	10.44_{75}	(44)	
	Hard drawn	20	10.44_{10}	(44)	
	Distilled (*in vacuo*)	20	10.49_{23}	(43)	
	Cast disc heated to redness	0	10.462_{4}	(93)	
	Same, struck	0	10.502_{8}	(93)	
	Reheated red	0	10.489_{4}	(93)	
	Struck again	0	10.510_{4}	(93)	
	Reheated (*in vacuo*)	0	10.497_{7}	(93)	
	Fine powder by precipitation or decomposition of Ag_2O and Ag_2CO_3		9.945 to 10.499	(46)	
Al	Cold rolled (99.97% Al)	20	2.699	(17)	SLA
	Cast, pig (99.75% Al)		2.684†	(18)	
	Cold rolled ½–¼ in.		2.703†	(18)	
	Cast (99.75% Al)**	20	2.703†	(18)	
As	Metallic	15	5.73	(49, 100)	CHD
	Yellow‡	18	2.0	(21, 47)	
	Amorphous‡	15	3.6_{9}	(49)	
	Black or gray	20	4.7	(21, 47)	
Au	Cast or cast and compressed	0	19.30	(53, 55, 86)	TKR
	Distilled, compressed by 10^4 atm	20	19.26_{85}	(43)	
	Drawn, annealed	20	19.26_{01}	(44)	
	Hard drawn	20	19.25_{04}	(44)	
	Precipitated from soln. by CH_2O	20	19.39_{66}	(8)	
	SO_2	15	19.35_{87}	(65)	
	Cold rolled sheet	0	19.296_{5}	(86)	
	Same, annealed	0	19.285_{8}	(86)	
B		20	2.3	(73)	CHD
Ba		25	3.5	(8)	CHD
Be		20	1.8_{4}	(22)	CHD
Bi		20	9.80	(40)	OFH
C	Graphite	20	2.25 to 2.26	(4)	VHS
	Graphite after compression to 5000 atm	15	2.255	(50)	
	Graphite, fused in arc	16	2.232	(51)	
Ca		20	1.5_{5}	(7, 52, 60)	CHD
Cd	Cast	20	8.648	(20, 43)	CHMJ
	Cast, compressed	20	8.647	(54)	
	(Computed value)	−273	9.65	(32)	
Ce		20	6.9	(62)	CHD
Co			8.9	(14, 45)	CHD
Cr			7.1	(79)	CHD
Cs		20	1.9_{0}	(31, 75)	CHD
Cu	Impurities negligible	20	8.9_{4} ±0.01	(26, 43, 64)	DH
Fe	Electrolytic: O_2, 0.08%; P, 0.007%; melted *in vacuo*, rolled down 80%; normalised 1000°C	20	7.90	(95)	DH
Ga		29.65	5.9_{1}	(74)	CHD
Ge		20	5.3_{6}	(18, 37)	CHD
Hf		20	11.4	(33)	Ed.
Hg		M.P.	14.43§	(16, 29, 36, 96)	Ed.
In		20	7.3_{1}	(77)	CHD

Part I.—Solid Metals.—(*Continued*)

Metal	Condition	Temp., °C	d_4^t	Lit.	Coop. exp.
Ir	Cast, hammered, slightly impure	0	22.4	(55, 63, 89)	TKR
K		20	0.86	(31, 75, 76)	CHD
La		15	6.1_{6}	(48, 82)	CHD
Li		20	0.53	(75)	CHD
Mg	Filings		1.742_{9}	(54, 65)	AP
		20	1.738_{8}	(19)	
		650	1.642		
Mn‖			7.2	(79)	CHD
Mo			10.2	(23)	CHD
Na		20	0.97	(28, 31, 75)	CHD
Nd		20	6.9	(82)	CHD
Ni			8.90± 0.05	(13, 25, 39)	PDM
Os	Crystals		22.48	(42, 90)	TKR
Pb		20	11.347_{5}	(20)	OFH
	Ordinary	19.94	11.337	(80)	
	Radioactive	19.94	11.289		
	Ordinary	16.34	11.347_{5}	(20)	
	From Australian uranium mineral	16.34	11.296		
Pd	Cast		11.87	(55)	TKR
	Cast, hammered	0	12.1	(54, 63, 65, 73, 78)	
Pr		20	6.5	(62)	CHD
Pt	Cast and hammered or struck	0	21.46	(58, 63, 75, 89, 92)	TKR
	In mass	0	21.33_{51}	(54, 65)	
	Filings		21.37_{05}	(54, 65)	
	Annealed wire	20	21.44_{08}	(44)	
	Hard drawn wire	20	21.41_{88}	(44)	
Rb		20	1.53	(75)	CHD
Rh	Cast		12.1	(88)	TKR
	Hard drawn wire		12.23	(30)	
	Cast and forged		12.5	(83, 103)	
Ru	Cast, pulverised	0	12.2	(41, 91)	TKR
Sa		20	7.7?	(62)	CHD
Sb		20	6.620	(43)	OFH
	Pressed		6.69	(43)	
	Rhombohedral		6.71	(53)	
Si¶	Crystalline	20	2.4	(79, 97)	CHD
Sn	White	20	7.30	(99)	OFH
	Gray		5.85	(99)	
Sr			2.6	(27)	CHD
Ta			16.6	(9)	CHD
Th			$11._{7}$	(72)	CHD
Ti			$4._{5}$	(35)	CHD
Tl		20	11.849	(104)	TKR
U			18.7	(101)	CHD
V		20	5.9_{6}	(37, 61)	CHD
W			19.3	(24)	CHD
Zn		20	7.13_{9}	(20)	CB
	Different distillation fractions, variable isotopic proportion		7.138_{1} to 7.142_{0}	(29, *v. also* 2, 12, 43, 102)	
Zr		20	6.4	(95)	CHD

* For effect of annealing, *v.* (86).
† Reduced *ad vacuum*.
‡ Probably not true allotropic forms.
§ $\frac{1}{V_{M.\,P.}}\frac{\Delta V}{\Delta t}$ = 0.000123 per °C between −70° and the M. P.
‖ No satisfactory determination on the homogeneous metal.
¶ Probably the only true form.
** Corresponding to values given below for density of liquid metal.

Part II.—Liquid Metals

Metal	Temp., °C	d_4^t	Lit.	Coop. exp.
Ag	M. P.	9.46	(82)	TKR
	M. P.	9.51	(70, 84)	
	1000	9.653	(34)	
	1025	9.633	(34)	
	1050	9.613	(34)	
Al*	659	2.382	(18)	SLA
	1000	2.289	(18)	
Bi	271	10.24	(69)	OFH
Cd		$8.02 - \delta(t - 320)$; $\delta = 11 \times 10^{-4}$	(36)	CHMJ
	349	7.94	(3)	
	406	7.88	(3)	
	466	7.82	(3)	
	506	7.78	(3)	
	550	7.74	(3)	
	603	7.69	(3)	
Cs	28	1.84	(31)	CHD
Ga	29.8	6.09	(74)	CHD
Hg	*v. infra.*			
K	62.4	0.83	(31)	CHD
Mg	650	1.572	(19)	AP
	667	1.560 to 1.565	(19)	
Na	97.5	0.93	(28, 31)	CHD
	B. P.	0.74	(71)	
Pb	327	10.88	(66)	OFH
Rb	38.5	1.47	(31)	CHD
Sb	631	6.55	(66)	OFH
Sn	232	6.97	(66)	OFH
Zn	418	6.92	(67)	CB
	455	6.87	(67)	
	510	6.79	(67)	
	574	6.72	(67)	
	661	6.65	(67)	
	800	6.57	(67)	
	918	6.53	(67)	

* 99.75% Al. Corresponding value for d at 20°, 2.703.

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Bureau of Standards, *365*, No. **100**; 21. (11) Burger, *208*, **2**: 114; 22. (12) Cohen and Helderman, *64P*, **16**: 565; 13. (13) Copaux, *6*, **6**: 508; 05. (14) Copaux, *34*, **140**: 657; 05. (15) Dennis, Tressler and Hance, *1*, **45**: 2033; 23. (16) Dewar, *135*, **91**: 216; 05. (17) Edwards, *78*, **47**: 287; 25. (18) Edwards and Moorman, *33*, **24**: 61; 21. (19) Edwards and Taylor, *80*, **69**: 1070; 23.

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(30) Grüneisen, *8*, **22**: 801; 07. (31) Hackspill, *34*, **152**: 259; 11. (32) Herz, *93*, **105**: 171; 19. (33) Hevesy, *137*, **6**, No. **7**: 51; 26. (34) Hoffmann and Stahl, *187*, **19**: 357; 22. (35) Hoffmann and Stahl, *187*, **21**: 22; 24. (36) Hogness, *1*, **43**: 1621; 21. (37) Hull, *2*, **20**: 113; 22. (38) Hunter, *1*, **32**: 330; 10. (39) International Nickel Co., New York, *O*.

(40) Johnston and Adams, *1*, **34**: 563; 12. (41) Joly, *34*, **116**: 430; 93. (42) Joly and Vèzes, *34*, **116**: 577; 93. (43) Kahlbaum, Roth and Siedler, *93*, **29**: 177; 02. (44) Kahlbaum and Sturm, *93*, **46**: 217; 05. (45) Kalmus and Harper, *45*, **7**: 6; 15. (46) Kohlschütter and Eydmann, *13*, **398**: 1; 13. (47) Kohlschütter, Frank and Ehlers, *13*, **400**: 268; 13. (48) Kremers and Stevens, *1*, **45**: 614; 23. (49) Lashchenko, *4*, **121**: 972; 22.

(50) Le Chatelier and Wologdine, *34*, **146**: 49; 08. (51) Lely and Hamburger, *93*, **87**: 209; 14. (52) Lengyel, *Math. Naturw. Ber. Ungarn*, **14**, 180; 98. (53) Linck, *93*, **56**: 393; 08. (54) Lowry and Parker, *4*, **107**: 1005; 15. (55) McKeehan, *2*, **20**: 424; 22. (56) Mallet, *3*, **4**: 145; 77. (57) Manchot, *93*, **124**: 333; 22. (58) Matthey, *5*, **28**: 463; 79. (59) Matthiessen, *62*, **150**: 177; 60.

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(70) Quincke, *8*, **135**: 621; 68. (71) Ramsay, *25*, **13**: 2145; 80. (72) Rentschler and Marden, Westinghouse Lamp Co., Bloomfield, N. J., *O*. (73) Richards, *1*, **37**: 1643; 15. (74) Richards and Boyer, *1*, **43**: 274; 21. (75) Richards and Brink, *1*, **29**: 117; 07. (76) Richards and Daniels, *1*, **41**: 1732; 19. (77) Richards and Sameshima, *1*, **42**: 49; 20. (78) Richards and Stull, *152*, **76**: 55; 07. (79) Richards, Stull and Brink, *152*, **76**: 29; 07.

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(90) Sainte-Claire Deville and Debray, *34*, **82**: 1076; 76. (91) Sainte-Claire Deville and Debray, *34*, **83**: 926; 76. (92) Stas, *Oeuvres complètes*, **II**: 719, 742; 94. (93) Stas, *Oeuvres complètes* (*Oeuvres Posthumus*) **III**: 153; 94. (94) Timofeiev, *7*, **86**: 113; 13. (95) Tritton and Hanson, *140*, **110**: 90; 24. (96) Vicentini and Omodei, *23*, **23**: 38; 87. (97) Weiss and Engelhardt, *93*, **65**: 38; 10. (98) Weiss and Neumann, *93*, **65**: 248; 10. (99) Wigand, *8*, **27**: 64, 99; 07.

(100) Zhemchuzhnui, *95*, **4**: 228; 13. (101) Zimmermann, *25*, **17**: 2739; 84. (102) Freeman and Brandt, *31*, No. **522**; 26. (103) Rose, *47*, **33**: 109; 25. (104) Richards and Smith, *1*, **44**: 524; 22.

Hg, DENSITY OF LIQUID MERCURY

V. Stott and Philip H. Bigg

The density of mercury at 0°C given in the table below is based on the following values: 13.59547 g/ml (Guye and Batuecas, *42*, **20**: 308; 23); 13.5956 g/ml (Marek, *238*, **2**: D; 83); 13.59545 g/ml (Thiesen and Scheel, *243*, **18**: 138; 98).

Densities at other temperatures were calculated by means of the formula: $V_t = V_0[1 + 10^{-6}\{181.456t + 0.009\,205t^2 + 0.000\,006\,608t^3 + 0.000\,000\,067\,320t^4\}]$ (Sears, *67*, **26**: 95; 13).

Chappuis' formula for the expansion of mercury between 0 and 100°C (Chappuis, *238*, **16**: 17) would give the same values between these temperatures as those tabulated on p. 458.

DENSITY AND SPECIFIC VOLUME IN MILLILITERS PER GRAM

t, °C	Density	Volume	*t*, °C	Density	Volume	*t*, °C	Density	Volume	*t*, °C	Density	Volume
(F. P.)						110	13.3278	0.075031	240	13.0176	0.076819
−38.87	13.6919	0.073036	45	13.4851	0.074156	120	13.3037	75167	250	12.9938	76960
−30	13.6698	73154	50	13.4729	74223	130	13.2797	75303			
−20	13.6450	73287				140	13.2558	75439	260	12.9700	0.077101
−10	13.6202	73420	55	13.4608	0.074290	150	13.2319	75575	270	12.9462	77243
± 0	13.5955	73554	60	13.4486	74357				280	12.9224	77385
			65	13.4365	74424	160	13.2080	0.075712	290	12.8986	77528
5	13.5832	0.073620	70	13.4243	74492	170	13.1841	75849	300	12.8747	77672
10	13.5709	73687	75	13.4122	74559	180	13.1603	75986			
15	13.5586	73754				190	13.1365	76124	310	12.8508	0.077816
20	13.5463	73821	80	13.4001	0.074626	200	13.1127	76262	320	12.8268	77962
25	13.5340	73888	85	13.3880	74694				330	12.8028	78108
			90	13.3759	74761	210	13.0889	0.076400	340	12.7787	78255
30	13.5218	0.073955	95	13.3639	74829	220	13.0651	76540	350	12.7546	78403
35	13.5096	74022	100	13.3518	74896	230	13.0414	76679	357.1	12.7374	0.078509
40	13.4973	74089							(B. P.)		

LATENT HEAT OF PHASE CHANGES OF PURE METALS AND ALLOYS

M. L. GAYLER

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE	PAGE

Conversion Factors: 1 kilojoule per g = 238.9 $cal_{15}\ g^{-1}$ = 430.1 $BTU_{60}\ lb^{-1}$ = 9.869 l-atm. $g^{-1} = 2.778 \times 10^{-4}$ kw hr g^{-1}. For other factors, *v.* vol. 1, p. 16.

TABLE 1.—LATENT HEAT OF FUSION OF PURE METALS

Metal	L_F, kilojoule per g-atom	Approx. error, %	M. P., °C	Lit.
Ag	11.7	5	961	(23)
Al	9.82	3	657	(6, 8, 17)
Au	13.1	5	1064	(23)
Bi	8.93	5	270	(8, 23)
Cd	5.21	3	321	(8, 23)
Cs	2.09	2	28.5	(14)
Cu	11.1	3	1084	(6, 15, 23)
Fe*	11.5	5		(23)
Ga	5.56†	2	30	(1)
Hg	2.34	3	−38.7	(10, 13)
K	2.40	2	63.5	(14)
Mg	7.3	7	650	(8, 17)
Na	2.63	1	97.61	(7, 14)
Ni	17.9	1	1450	(22)
Pb	4.86	3	327	(8, 23)
Pd	16.1	10		(20)
Pt	22.0	10		(19)
Rb	2.18	1	38.7	(14)
Sb	19.8	3	630	(8, 23)
Sn	6.67	2	232	(6, 8, 23)
Tl	6.15‡			(16)
Zn	6.97	5	419	(8, 23)

* Electrolytic Fe.

† L_F determined on super-cooled liquid at 13 and 14°C. The mean of these determinations is given and the author states that there is practically no difference in L_F between 0 and 30°C.

‡ Method not stated.

TABLE 2.—LATENT HEAT OF VAPORIZATION AT *p* MM HG

Metal	L_V, kilojoule per g-atom	Approx. error, %	*p*, mm Hg	Lit.
Bi	141		2×10^{-3}	(21)
Cd	84.7		2×10^{-3}	(21)
Hg	53.3		2×10^{-3}	(21)
Hg	57	4	760	(11)
Mg	172.7		2×10^{-3}	(21)
Zn	99.8		2×10^{-3}	(21)

TABLE 3.—LATENT HEAT OF TRANSFORMATION

Metal	Transformation	L_T, kilojoule per g-atom	t_T,°C	Lit.
Ag	β (octohedral) → α	13.7*		(12)
As	α (rhombohedral) → β (amorphous gray)	4.18*		(12)
	γ (amorphous brown) → α (rhombohedral)	14.0*		(12)
	Amorphous → crystalline	4.2*		(3)
Au	β (dark) → α (bright)	13.4*		(12)
	γ (metallic) → α (bright)	19.6*		(12)
Fe†	α → β	1.53	725–785	(23)
	β → γ	1.56	919	(23)
	γ → δ	0.45	1404	(23)
Mn	α → β	5.55	1070–1130	(23)
Ni	α → β	0.326	320–330	(23)
Sb	α (explosive) → ordinary	9.97*		(5)
Se	α (amorphous) → β (monoclinic)	4.39*		(12)
	α (amorphous) → γ (crystalline)	5.98*		(12)
	Amorphous → metallic	23.7*		(2)
Sn	White → gray	2.22	0	(4)
Te	Crystalline (sublimed) → amorphous	101*		(2)

* Difference between heats of oxidation.

† Electrolytic Fe.

TABLE 4.—LATENT HEAT OF FUSION OF ALLOYS

Alloy	L_F, kilojoule per g	Approx. error, %	M. P., °C	Lit.
Al_2Cu	0.31	7	590	(17)
$MgZn_2$	0.26	7	595	(17)
Monel metal (Ni, 68; Cu, 28; Fe, 2; Mn, 1.5)	0.284	1		(22)
Pig iron, 4.34 % C	0.246			(18)
Gray cast iron	0.09_5	12	1350–1400	(9)
White cast iron	0.14	12	1050–1100	(9)

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Koref, *8*, **36**: 49; 11. (11) Kurbatov, *7*, **43**: 104; 03. (12) Petersen, *7*, **8**: 601; 91. (13) Pollitzer, *93*, **17**: 10; 11. (14) Rengade, *34*, **156**: 1897; 13. (15) Richards, *135*, **68**: 82; 93. (16) Robertson, *182*, **18**: 131; 02. (17) Roos, *93*, **94**: 329; 16. (18) Schmidt, *192*, **7**: 164; 10. (19) Violle, *34*, **85**: 543; 77.

(20) Violle, *34*, **87**: 981; 78. (21) Wehnelt and Musceleanu, *88*, **14**: 1032; 12. (22) White, *33*, **25**: 17; 21. (23) Wüst, Meuthen and Durrer, *414*, No. **204**: 18.

THERMAL EXPANSION INCLUDING VOLUME CHANGE ON FUSION, SOLIDIFICATION AND TEMPERING

J. S. CLARK

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COEFFICIENTS OF EXPANSION OF PURE METALS

Definitions

l = length; V = volume; t = temperature, °C.

LINEAR — CUBICAL

$$\alpha_{t_1}^{t_2} = \frac{l_2 - l_1}{l_1(t_2 - t_1)}; \qquad A_{t_1}^{t_2} = \frac{V_2 - V_1}{V_1(t_2 - t_1)} \qquad \text{(Mean coefficients)}$$

LINEAR — CUBICAL

$$\alpha_t = \frac{dl}{l\,dt}; \qquad A_t = \frac{dv}{V\,dt} \qquad \text{(True coefficients)}$$

$$l_t = l_0(1 + \alpha t + \beta t^2 + \gamma t^3 + \delta t^4 + \ldots);$$
$$V_t = V_0(1 + At + Bt^2 + Ct^3 + \ldots)$$

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS

Metal	Range, °C	$10^6\alpha$*	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Ag	−200 to 300	18.7	5.9	−25.33$_\gamma$ 53.3$_\delta$	±0.5	(68, 88) (50, 74, 123)
	−200 to 0	16.1				Comp.†
	0 to 300	19.6				Comp.†
	−170 to 0	19.5	3.7	−37$_\gamma$		(1)
	0 to 900	20.5				(84)
Al	−200 to 0	22.65	16.75	−36.67$_\gamma$	±0.03, 0°	(1, 68)
	−200	11.55				Comp.†
	−100	18.2				Comp.†
	0 to 600	22.65	9.5		±0.03, 0°; ±0.8, 600°	(37, 50, 80, 84, 91, 125, 129)
99.95	0 to 600	22.58	9.89			(70)
99.74	0 to 600	21.90	12.0		±0.2	(129)
99.15	20 to 200	25.9				(70)
	20 to 400	27.2				(70)
	20 to 600	28.7				(70)
Hard drawn	0 to 100	24.32				(17)
Annealed	0 to 100	24.54				(17)
As	10 to 90	3.86	21.6	Sublimed; mixed crystals		(50)
Au	−100 to 500	14.13	2.768	−0.911$_\gamma$	±0.1	(39, 40, 50, 56, 98)
	−100 to 0	13.84				Comp.†
	0 to 100	14.40				Comp.†
	100 to 300	15.1				Comp.†
	300 to 500	15.9				Comp.†

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS—(*Continued*)

Metal	Range, °C	$10^6\alpha$*	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Bi	−183 to 15	12.98				(56)
	−183 to 15	12.24				(39)
	19 to 101	13.45				(56)
	16 to 35	13.43				(139)
	0 to 270	14.6				(138)
	8 to 180	15.7				(91)
∥	10 to 90	15.37	10.45			(50)
∥	20	13.96				(16)
∥	20 to 240	16.2‡			±0.1	(116)
⊥	10 to 90	10.84	15.55			(50)
⊥	20	10.36				(16)
⊥	20 to 240	12.0‡			±0.1	(116)
Ca	0 to 21	25	Calculated from cubical coefficients			(15)
C		Graphite, *v.* Table 11				
Cd ∥	−160	59.0			*v. also* Fig. 1	(57)
∥	60	52.5				(57)
⊥	−160	12.2				(57)
⊥	60	21.8				(57)
Mean (calc.)	−160	27.8	Mean (calc.) $\frac{\alpha\| + 2\alpha\perp}{3}$			(57)
Mean (calc.)	60	32.0				(57)
Mean (obs.)	−170 to 200	29.1	17.9			(39, 50)
Mean (obs.)	0 to 315	38				(138)
Co	6 to 120	12.08	6.4			(136)
	25 to 350	18.1				(108)
Cr	0 to 500	8.11	3.23			(36)
	− 78 to 0	7.31				(36)
98.3 (+Al, Fe, etc.)	0	6.8				(24)
98.3 (+Al, Fe, etc.)	200	9.0				(24)
98.3 (+Al, Fe, etc.)	300	9.8				(24)
98.3 (+Al, Fe, etc.)	600	12.3				(24)
98.3 (+Al, Fe, etc.)	900	14.7				(24)
Cs	0 to 26	97	Calculated from cubical coefficients			(64)
Cu	−100 to 400	16.2	9.5	-20_γ 23_δ	±0.2, 0° ±0.4, 400°	(50, 68) (37, 69)
	−250 to −193	3.9				(88)
	−193 to −183	6.8			*also* Fig. 2	(88)
	−187 to 19	12.3				(88)
	0 to 1000	20.0				(84)
Cu, 99.6; Ni, 0.35	25 to 300	16.7	3.3	*Idem.* for Cu, 99.4; As, 0.54		(69)
Fe	0 to 700	11.45	7.0	-3.63_γ 1.2_δ	±0.3	(41, 63, 74, 130)
	0 to 100	12.1				Comp.†
	0 to 300	13.2				Comp.†
	0 to 500	14.2				Comp.†
	0 to 700	15.0				Comp.†
	−190 to 20	9.18				(39, 68)
	>890§	*ca.* 23				(63)
Ga	0 to 30	18.3	Calculated from cubical coefficients			(114)
In	10 to 90	24.75	211.9			(50)
Ir	−150 to 800	6.41	3.197	-4.333_γ 2.629_δ	±0.2, −150° ±0.1, 600°	(56, 137) (5, 50, 76)
	−150 to −50	5.64				Comp.†
	− 50 to 50	6.40				Comp.†
	50 to 150	6.92				Comp.†
	150 to 300	7.3				Comp.†
	300 to 800	7.8				Comp.†
	1000	9.02				(76)
	1250	9.60				(76)
	1500	10.18				(76)
	1750	10.76				(76)

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS.—(*Continued*)

Metal	Range, °C	$10^6\alpha$*	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
K	0 to 50	83.3				(65)
	0 to 56	79.7	69.7	Calculated from cubical coefficients		(65)
	0 to 58	70.4	51.7			(6)
	0 to 58	72.0				(64)
Li	0 to 178	51.2	31	Calculated from cubical coefficients		(6)
Mg	−150 to 500	25.0	15.0	-11.6_γ	±1.0, −100°; ±0.5 from 0 to 500°	(50, 72) (56, 123)
	−100 to 0	23.4				Comp.†
	0 to 100	26.4				Comp.†
	0 to 300	28.5				Comp.†
	0 to 500	29.6				Comp.†
Mn	−190 to 20	23.03	37.2			(36)
	0 to 300	21.61	12.1			(36)
Mo	−190 to 20	5.1	5.7			(36, 120)
	0 to 400	5.1	1.3			(36, 120)
W, 1.85% (*v. also* Table 34)	25 to 100	5.2				(71)
	25 to 250	5.4				(71)
	25 to 500	5.6				(71)
	500 to 600	6.2				(71)
	600 to 700	6.4				(71)
	500 to 750	6.3				(71)
99.86 to 99.98 (+Fe, Si, Cu)	25 to 100	3.7 to 5.0				(71)
	25 to 250	4.4 to 5.1				(71)
	25 to 500	4.7 to 5.7				(71)
Na	−191 to 17	62.2				(35)
	0 to 50	72.1				(65)
		69				(13, 14)
	0 to 90	64	87	Calculated from cubical coefficients		(6, 55, 64, 65)
Ni	−200 to 350	12.54	8.75	-7.5_γ; 6.25_δ	1.0, −200°; ±0.1, 0°; ±0.4, 300°	(58, 63, 136) (30, 36, 74) (66, 112)
	−100 to 0	11.6				Comp.†
	0 to 100	13.3				Comp.†
(*v. also* Table 35)	100 to 200	14.7				Comp.†
	200 to 300	15.9				Comp.†
	350 to 550	*ca.* 19.0	Critical region			(66)
	500 to 1000	13.46	3.31			(74)
	0 to 1000	18.2				(84)
Commercial, 94 to 99%	25 to 100	12.9 to 13.5				(129)
	25 to 300	13.8 to 14.6				(129)
	25 to 600	14.9 to 15.7				(129)
Os	10 to 90	5.70	10.9			(50)
Pb	−200 to 150	28.3	12	-13.3_γ; 75_δ	±1.0	(39, 40, 50, 56, 88, 113)
	−200	19.5				Comp.†
	−100	25.2				Comp.†
	100	30.6				Comp.†
	0 to 320	33				(138)
Pd	−200 to 100	11.60	4.15	-8.67_γ	±0.3, −100°; ±0.1, 0°	(50, 68, 74, 121)
	−200 to −100	9.75				Comp.†
	−100 to 0	11.10				Comp.†
	0 to 100	11.93				Comp.†
	0 to 1000	11.67	2.19			(74)
Pt	−150 to 600	8.786	3.118	-5.2_γ; 4.095_δ	±0.1, −100°; ±0.05, 0°; ±0.1 from 100 to 600°	(5, 50, 68, 74, 103, 121, 124, 137)
	−150 to −50	7.97				Comp.†

TABLE 1.—THERMAL COEFFICIENT OF LINEAR EXPANSION OF METALS.—(*Continued*)

Metal	Range, °C	$10^6\alpha$*	$10^9\beta$	$10^{12}\gamma$ and $10^{15}\delta$	Probable error of $10^6\alpha$	Lit.
Pt.—(*Continued*)	− 50 to 50	8.76				Comp.†
	50 to 150	9.26				Comp.†
	150 to 300	9.6				Comp.†
	300 to 600	10.0				Comp.†
	800	10.98				(74)
	1000	11.51				(15)
	0 to 1670	9.75				(126)
Rb	0 to 38	90	Calculated from cubical coefficients			(64)
Rh	−180 to 100	8.19	4.217	-7.0_γ	±0.1, < −100°	(50, 137)
				51.67_δ	±0.05, > −100°	(50, 137)
	−180 to −100	6.5				Comp.†
	−100 to 0	7.65				Comp.†
	0 to 100	8.59				Comp.†
Ru	10 to 90	8.51	14.05			(50)
Sb	−190 to 17	10.22				(56, 137)
	17 to 100	10.88				(56, 137)
	9 to 72	11.77				(91)
	10 to 90	11.29	2.9			(50)
‖	10 to 90	17.3	−4.7			(50)
‖	20	15.56				(16)
⊥	−180 to 20	8.2				(39)
⊥	10 to 90	8.28	6.7			(50)
⊥	20	7.96				(16)
⊥	100 to 300	10.0				(12)
Si	−191 to 18	2.5	7.7			(137)
	0 to 100	6.95	8.5	*v. also* Table 37		(50)
Sn, 99.9%	−163 to 18	16				(29)
White	10 to 90	20.9	17.5			(50)
White	20 to 232	23 to 24				(29, 138)
Gray	−163 to 18	5.3				(29)
Single crystals ‖	20	30.5				(16)
Single crystals ⊥	20	15.45				(16)
Ta	−78 to 0	5.9				(36)
	0 to 400	6.46	0.9			(36)
Tl	10 to 90	25.65	57.0			(50)
	0 to 294	33				(102)
W	−190 to 0	3.8				(36)
	0 to 400	4.46	0.73			(36)
99.99	17 to 577	4.5				(53)
99.99	577 to 1377	5.71				(53)
99.99	1377 to 2227	7.27				(53)
W, 99; Th, 1	20 to 675	4.56				(38)
	27	4.44				(141)
	1027	5.19				(141)
	2027	7.26				(141)
	−150 to 502	4.28	0.58		¶	(71.2)
	30 to 630	4.67**		$l_t = l_{t_1}[1 + \alpha(t - t_1) + \beta(t - t_1)^2]$		(52)
	630 to 830	4.00**				(52)
	830 to 2430	4.87**	9.45			(52)
Zn	−170 to 60	29.5	21.6	-40_γ		(39, 40, 50, 57)
	0 to 300	35.4	10			(125)
99.99	20 to 250	39.5	(Cast)			(70)
‖	−160 to 60	57 to 64				(16, 57)
⊥	−160	6.6			*v. also* Fig. 1	(57)
⊥	20	12.6				(16)
⊥	60	15.6				(57)
	−220 to 60	13.5	2.37			(56, 57, 88)

* If only α is given and only one temperature, $\alpha = \alpha t$; if only α and a temperature range, $\alpha = \alpha_{t_1}^{t_2}$.
† Computed, using the above values of α, β, γ, δ.
‡ Practically constant between 20 and 240°C.
¶ Probable error of $l_t = \pm 8 \times 10^{-4}$%.
** Aged lamp filaments.
§ Critical temperature.

TABLE 2.—THERMAL COEFFICIENT OF CUBICAL EXPANSION OF METALS (SOLID)

$$V_t = V_0\,(1 + At + Bt^2)$$

Metal	Range	10^6A	10^9B	Lit.
Ca	0 to 21°C	75		(15)
Cs	0 to 26°C	291		(64)
Ga	0 to 30°C	55		(114)
Hg; *v.* p. 456				
K	0 to 50°C	239	209	(65)
	0 to 56°C	211.2	155	(6)
	0 to 58°C	250		(64)
Li	0 to 178°C	153.5	92	(6)
Na	−191 to 16°C	186.5		(35)
	0 to 78°C	181.6	280	(6)
	0 to 95°C	204	242	(65)
	0 to 80°C	216		(64)
	25 to 100°C	226		(55)
Rb	0 to 38°C	270		(64)
	1.6 to 17.5°C	268.6		(34)

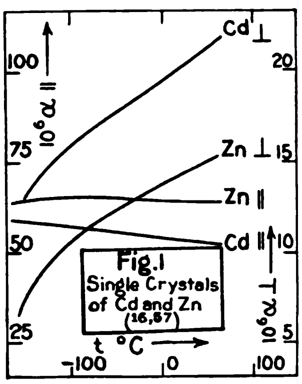


TABLE 3.—SPECIFIC GRAVITY AND THERMAL COEFFICIENT OF CUBICAL EXPANSION OF LIQUID METALS

$$V_t = V_\theta\ [1 + A(t-\theta) + B(t-\theta)^2 + C(t-\theta)^3 + \ldots],\ °C$$

Metal	Approx. M. P., θ°C	d_4^θ	10^6A	10^9B	Range, °C	Lit.
Ag	960	9.51				(117)
$d_4^{18.5}$ = 10.33		9.32	111		960 to 1100	(118)
Al 99.8	658	2.382	114		650 to 1100	(43)
99.4	658	2.384			650 to 1100	(43)
98.3	658	2.405			650 to 1100	(43)
99.4	658	2.41	142		658 to 1000	(105)
98.7 to 99.2	658	2.399	125		658 to 882	(9)
Au	1063	(17.1)				(109)
Bi	275	10.07	124		269 to 472	(73)
		10.00	120		270 to 300	(135)
		10.055				(117)
		10.03	121		360 to 630	(11)
Cd, electrolytic	320	7.99	170		318 to 351	(135)
		8.02	137		320 to 544	(73)
Cu 99.9	1083	8.40	62; 10^{12}C = 5600	−560	1083 to 1295	(105)
		8.22				(117)
		7.99	199		1083 to 1200	(9)
Cs	26	1.836	379		27 to 40	(42)
			395		27 to 100	(42)
			341		28 to 50	(64)
			348		50 to 123	(64)
Fe: C, 0.1%	1530	7.0				(117)
Fe: C, 0.2–0.25%	1540	6.92±0.07				(4)
Fe: C, 3.3; Si, 2.76%*	1150	6.97				(119)
Hg; *v.* p. 457						
K	62	0.8298	299		62 to 100	(65)
			280		70 to 100	(64)
			285		100 to 150	(64)
			268	210	78 to 235	(6)

TABLE 3.—SPECIFIC GRAVITY AND THERMAL COEFFICIENT OF CUBICAL EXPANSION OF LIQUID METALS.—(*Continued*)

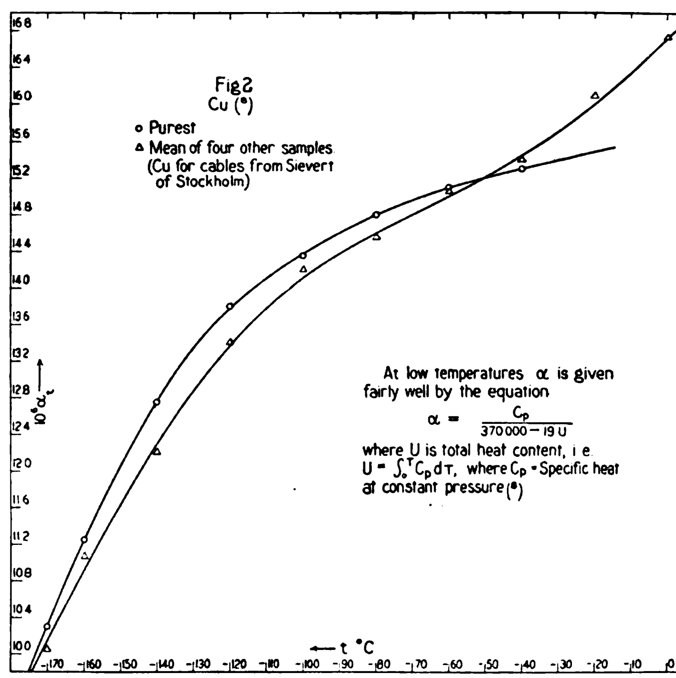
$$V_t = V_\theta\ [1 + A(t-\theta) + B(t-\theta)^2 + C(t-\theta)^3 + \ldots],\ °C$$

Metal	Approx. M. P., θ°C	d_4^θ	10^6A	10^9B	Range, °C	Lit.
Li	185		174	106	185 to 235	(6)
Mg	650	1.572 (1.545 at 780°)	(380)		650 to 800	(44) (118)
Na	98	0.9287	278		98 to 170	(65)
			275		100 to 180	(64)
			260	286	100 to 235	(6)
			390†		98 to 750	(110, 111)
Pb	327	10.65	129		325 to 357	(135)
		10.69	120		327 to 825	(33)
Pb, electrolytic		10.71	130		327 to 522	(73)
		(10.47 at 500±5°)				(4)
Pd	1550	(10.8)				(109)
Pt	1755	(18.9)				(109)
Rb	38	1.472	339		40 to 140	(64)
Sb, 99.9%	630	6.55	41	120	631 to 1074	(105)
		6.49	104		700 to 1040	(10)
Sn, electrolytic 99.9%	232	6.97	105		400 to 700	(11)
		7.01	106		232 to 396	(73)
		6.98	126; 10^{12}C = 146	−171	232 to 988	(102)
		6.98	100		232 to 1600	(33)
		6.99	114			(135)
		7.025				(117)
		(6.95 at 320±5°)				(4)
Tl	300	11.032	150		302 to 351	(102)
Zn, electrolytic 99.9%	419	6.59	147		419 to 543	(73)
		6.92	217	−198	419 to 918	(105)

The values in parentheses in the d_4^θ column are very old single determinations and are probably only approximate.

* Gray pig iron.

† Based on Ramsay's value of density at B. P.



COEFFICIENTS OF EXPANSION OF SOLID ALLOYS

First consult Table 4, which is a complete index of the section. The arrangement is alphabetical under the chemical symbol of the major constituent, as explained above, p. 360.

For definitions and symbols, *v.* p. 392.

Table 4.—General Table

Ag-Au; *v.* Table 38.

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ag-Cu					
Ag, 77; Cu, 23	1253	0 to 800	18.0		(84)
Ag-Hg-Zn; *v.* Table 32.					
Ag-Pt; *v.* Table 38.					
Al-Cr-Ni-Cu-Mn					
Al, 95.5; Ni, 1.5; Cr, 1.5; Cu, 1.0; Mn, 0.5	1452	14 to 302	21.05	14.73_β	(70)
Al-Cu; *v. also* Table 5 and Fig. 3					
Al, 95; Cu, 5 to Al, 87; Cu, 13		20 to 100	22.2–24.6		(70)
		20 to 200	23.6–26.8		(70)
		20 to 300	26.4–29.2		(70)
Al, 82; Cu, 18		15 to 100	21.9		(85)
Al, 70; Cu, 30		15 to 100	20.0		(85)
Al, 67; Cu, 33		15 to 100	16.2		(85)
Al, 50–0; Cu, 50–100		15 to 100	15.7–16.5		(85)
Al-Cu-Mg-Si; *v. also* Table 6					
Al, 94.4–94.8; Cu, 3.66–3.74; Mg, 0.36–1.08; (Mn, Fe, Si)	508	20 to 100	21.9–23.8		(70)
		20 to 200	22.9–26.0		(70)
		20 to 300	24.7–26.9		(70)
		20 to 400	25.7–27.3		(70)
		20 to 500	25.4–27.6		(70)
Al-Mg					
Al, 96; Mg, 3 (Fe, Sb)	824	0 to 13	22.0		(81)
Al, 85.9; Mg, 17.7 (Si, Fe, Cu)	824	12 to 39	23.8		(132)
Al-Mn-X; *v.* Table 7.					
Al-Cu-Si; Al-Mn; Al-Mn-Cu; *v.* Table 7.					
Al-Si; *v. also* Table 8					
Al, 95; Si, 5 to Al, 87; Si, 13		20 to 100	19.2–22.2		(70)
		20 to 200	20.2–23.2		(70)
		20 to 300	22.2–24.8		(70)
Al-Si-Cu; Al-Si-Mn-Cu; *v.* Table 7.					
Al-Zn; *v. also* Tables 9 and 10, and Fig. 4					
Al, 86; Zn, 14 to Al, 5; Zn, 95; *v.*		20 to 100	24.3–33.3		(70)
		20 to 200	27.3–37.2		(70)
		20 to 300	28.3–40.7		(70)
Al, 100; Zn, 0 to Al, 0, Zn, 100		25 to 250	27.1–32.6		(128)
		20 to 250	27.7–38.2		(128)
Al-Cu-Fe-Mn-Si; *v.* Table 7.					
Au-Ag; *v.* Table 38.					
Au-Cu; *v. also* Table 38					
Au, 91.66; Cu, 8.33		0 to 85	14.57	3.19_β	(5)
Bi-Pb; *v.* Table 38.					
Bi-Sn; *v.* Table 38.					
C (Graphite); *v.* Table 11.					
Cd-Pb; *v.* Table 38.					
Co-Cr; *v. also* Table 12					
Co, 55–80; Cr, 20–40 + C, W	1344	20 to 600	13.6–16.5		(129)
Co, 55; Cr, 35; W, 10	1345	−94 to 19	10.2		(129)
Co-Cr-W-C (Stellite); *v.* Table 12.					
Cr-Fe-C-Si; Cr-Fe-Si-C; *v.* Table 13.					
Cu-Al; *v. also* Al-Cu and Fig. 3					
Cu, 92.2; Al, 7.3; Zn, 0.4 (R_h)	103	20 to 300	15.57	8.05_β	(69)
Same, D_c		20 to 300	15.79	6.45_β	(69)
Cu-Ni					
Cu, 60; Ni, 40	405	−191 to 16	12.22		(68)
Cu, 60; Ni, 40	405	0 to 500	14.81	4.02_β	(74)
Cu-Sb; *v. also* Fig. 3					
Cu, 100; Sb, 0		25 to 100	16.3		(85)
Cu, 95; Sb, 5		25 to 100	19.2		(85)
Cu, 90; Sb, 10		25 to 100	20.2		(85)
Cu, 85; Sb, 15		25 to 100	20.0		(85)
Cu, 80; Sb, 20		25 to 100	19.2		(85)
Cu, 57; Sb, 43		25 to 100	14.5		(85)
Cu, 33; Sb, 67		25 to 100	11.5		(85)
Cu, 10; Sb, 90		25 to 100	9.1		(85)
Cu, 0; Sb, 100		25 to 100	10.0		(85)
Cu, 100; Sb, 0		100 to 300	16.4		(12)

Table 4.—General Table.—(*Continued*)

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Cu-Sb.—(*Continued*)					
Cu, 96; Sb, 4		100 to 300	17.9		(12)
Cu, 93; Sb, 7		100 to 300	19.1		(12)
Cu, 85; Sb, 15		100 to 300	20.0–20.5		(12)
Cu, 68; Sb, 32		100 to 300	23.3–23.8		(12)
Cu, 61.4; Sb, 38.6		100 to 300	23.4–24.2	Cu_2Sb	(12)
Cu, 60; Sb, 40		100 to 300	23.3–24.2		(12)
Cu, 55; Sb, 45		100 to 300	23.0–23.8		(12)
Cu, 50; Sb, 50		100 to 300	21.6–22.5		(12)
Cu, 45; Sb, 55		100 to 300	20.0–21.6		(12)
Cu, 28; Sb, 72		100 to 300	17.4		(12)
Cu, 3; Sb, 97		100 to 300	11.2		(12)
Cu, 1; Sb, 99		100 to 300	9.3		(12)
Cu, 0; Sb, 100 cast		100 to 300	10.0		(12)
Same, agglomerate		100 to 300	8.3		(12)
Cu-Si; *v. also* Table 15.					
Cu-Si, 3	452	15 to 900	17.88		(2)
Cu-Si, 6		15 to 900	17.83		(2)
Cu-Si, 10		15 to 700	16.08		(2)
Cu-Si, 55		15 to 1000	3.87		(2)
Cu-Si-Fe; *v.* Table 15.					
Cu-Sn					
Cu, 95.4; Sn, 4.25; P, 0.37	1082	20 to 300	16.81	3.59_β	(69)
Cu, 94.9; Sn, 4.88; P, 0.12	345	20 to 300	16.63	3.67_β	(69)
Cu, 92.0; Sn, 7.67; P, 0.11	664	20 to 300	16.82	4.25_β	(69)
Cu, 89.7; Sn, 10.14 (R_c)	664	20 to 300	17.13	3.70_β	(69)
Cu-Zn; *v. also* Tables 16, 17 and 38 and Fig. 6					
Cu, 97–65; Zn, 3–35		25 to 300	17.7–20.8		(69)
Cu, 60; Zn, 40	918	25 to 300	20.7–21.2		(69)
Cu, 88–62; Zn, 35–10; Pb, 1.65–2.57	777	25 to 300	18.3–20.4		(69)
Cu, 56.39; Zn, 40.59; Sn, 1.52; Fe, 0.96; Mn, 0.09; Pb, 0.09 (R_h)	842, 845	25 to 300	21.5–22.7		(69)
Cu-Zn-Pb; *v.* Table 16.					
Cu-Zn-Sn; *v.* Table 17.					
Fe-C; *v. also* Tables 18, 19, 20, 23, 28 and 31 and Fig. 7					
Fe with C, 3–4	661	−191 to 16	8.5		(68)
Fe with C, 3.12; Si, 3.37	661	0 to 700	8.3	8.3_β	(83)
Fe with C, 3.08; Si, 1.68	661	25 to 100	8.4		(130)
		100 to 200	11.7		(130)
		200 to 300	14.2		(130)
		300 to 400	15.6		(130)
		400 to 500	14.3		(130)
Fe with C, 3.04; Si, 1.65; P, 1.3; Mn, 0.2	661	15 to 1000	13.34		(2)
Same, Tp, 1000°; Q_w 15°		15 to 1000	14.02		(2)
Fe with <1.4 C		−200	5.8– 8.4		(23)
Fe with < 3.8 C		20 to 1000	13.1–19.6		(21)
		25 to 600	14.3–14.6		(22)
		> Crit. temp.	*ca.* 23		(22)
Fe with C <1.5; Mn, 0.27–0.67		15 to 75	10.8–12.1		(20)
Fe-Co-Cr-C					
Fe, 55.3; Co, 22.5; Cr, 21.2; C, 0.7.	588	20 to 100	15.6		(129)
		100 to 200	16.7		(129)
		200 to 300	17.6		(129)
		300 to 400	17.8		(129)
		400 to 500	17.6		(129)
		500 to 600	17.0		(129)
Fe-Cr-C; *v. also* Tables 13, 21, 22, 28, 29 and 31					
Fe-Cr, 13, etc		20 to 600	11.2–12.1		(22)
Fe; Cr, 3.1–7.4; Si, 0.5–2.4		15 to 900	12.6–14.9		(2)

Fe-Cr-Mo-C; *v.* Table 28.
Fe-Cr-Si-C; *v.* Table 31.
Fe-Cr-V-C; *v.* Tables 28 and 29.
Fe-Cu-Cr-C; *v.* Table 28.

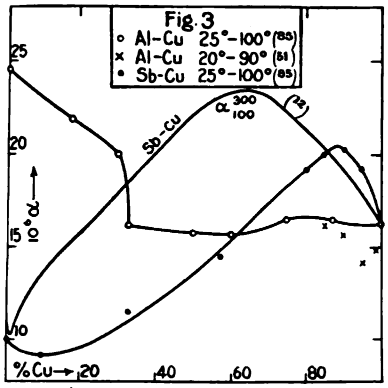


Fig. 3
Al-Cu 25°-100° (85)
Al-Cu 20°-90° (51)
Sb-Cu 25°-100° (85)
Sb-Cu
α^{300}_{100} (12)
$10^6\alpha$
%Cu → 20 40 60 80

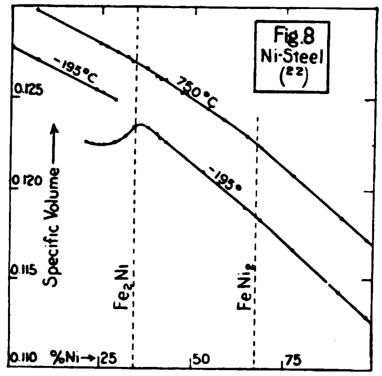


Fig. 8
Ni-Steel
(22)
-195°C
750°C
-195°
Specific Volume
Fe_2Ni
$FeNi_3$
%Ni → 25 50 75

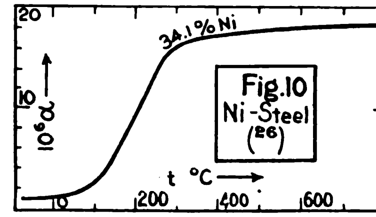


Fig. 10
Ni-Steel
(26)
34.1% Ni
$10^6\alpha$
t °C →
200 400 600

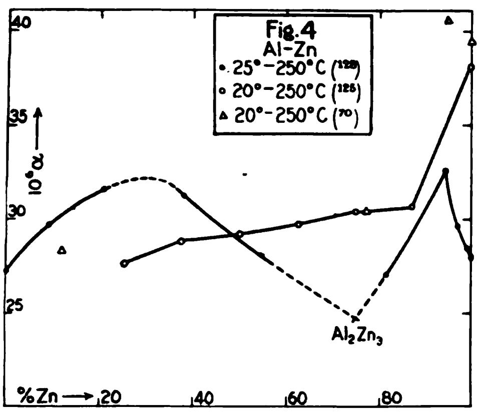


Fig. 4
Al-Zn
25°-250°C (128)
20°-250°C (125)
20°-250°C (70)
$10^6\alpha$
Al_2Zn_3
%Zn → 20 40 60 80

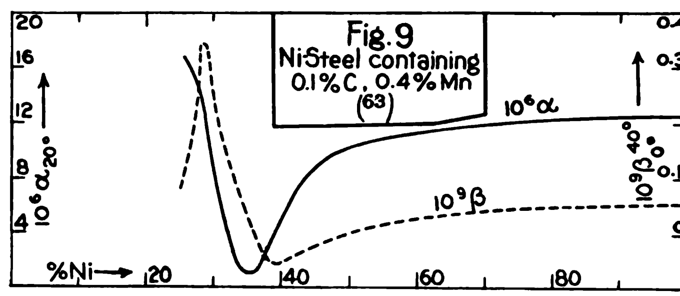


Fig. 9
Ni-Steel containing
0.1% C, 0.4% Mn
(63)
$10^6\alpha$
$10^9\beta$
$10^6\alpha_{20°}$
$10^9\beta_{0°}^{40°}$
%Ni → 20 40 60 80

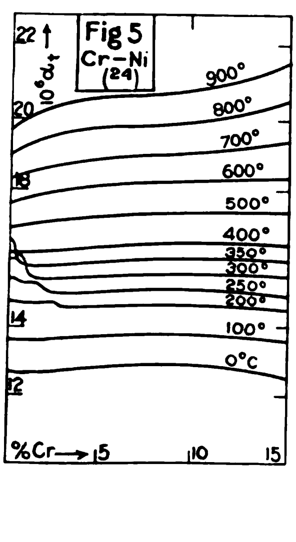


Fig 5
Cr-Ni
(24)
$10^6\alpha_t$
900°
800°
700°
600°
500°
400°
350°
300°
250°
200°
100°
0°C
%Cr → 5 10 15

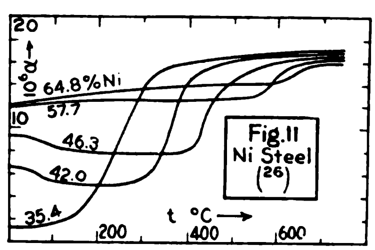


Fig. 11
Ni Steel
(26)
64.8% Ni
57.7
46.3
42.0
35.4
$10^6\alpha$
t °C →
200 400 600

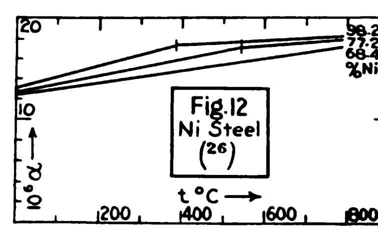


Fig. 12
Ni Steel
(26)
98.2
77.2
68.4
%Ni
$10^6\alpha$
t °C →
200 400 600 800

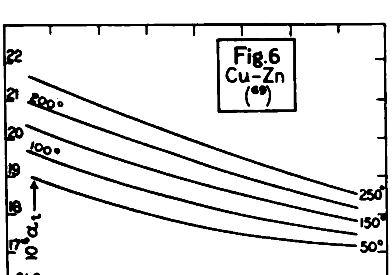


Fig. 6
Cu-Zn
(69)
200°
100°
250°
150°
50°
$10^6\alpha_t$
%Cu → 70 80 90

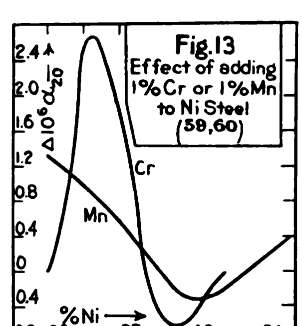


Fig. 13
Effect of adding
1% Cr or 1% Mn
to Ni Steel
(59, 60)
Cr
Mn
$\Delta 10^6\alpha_{20}$
%Ni →
30 38 46 54

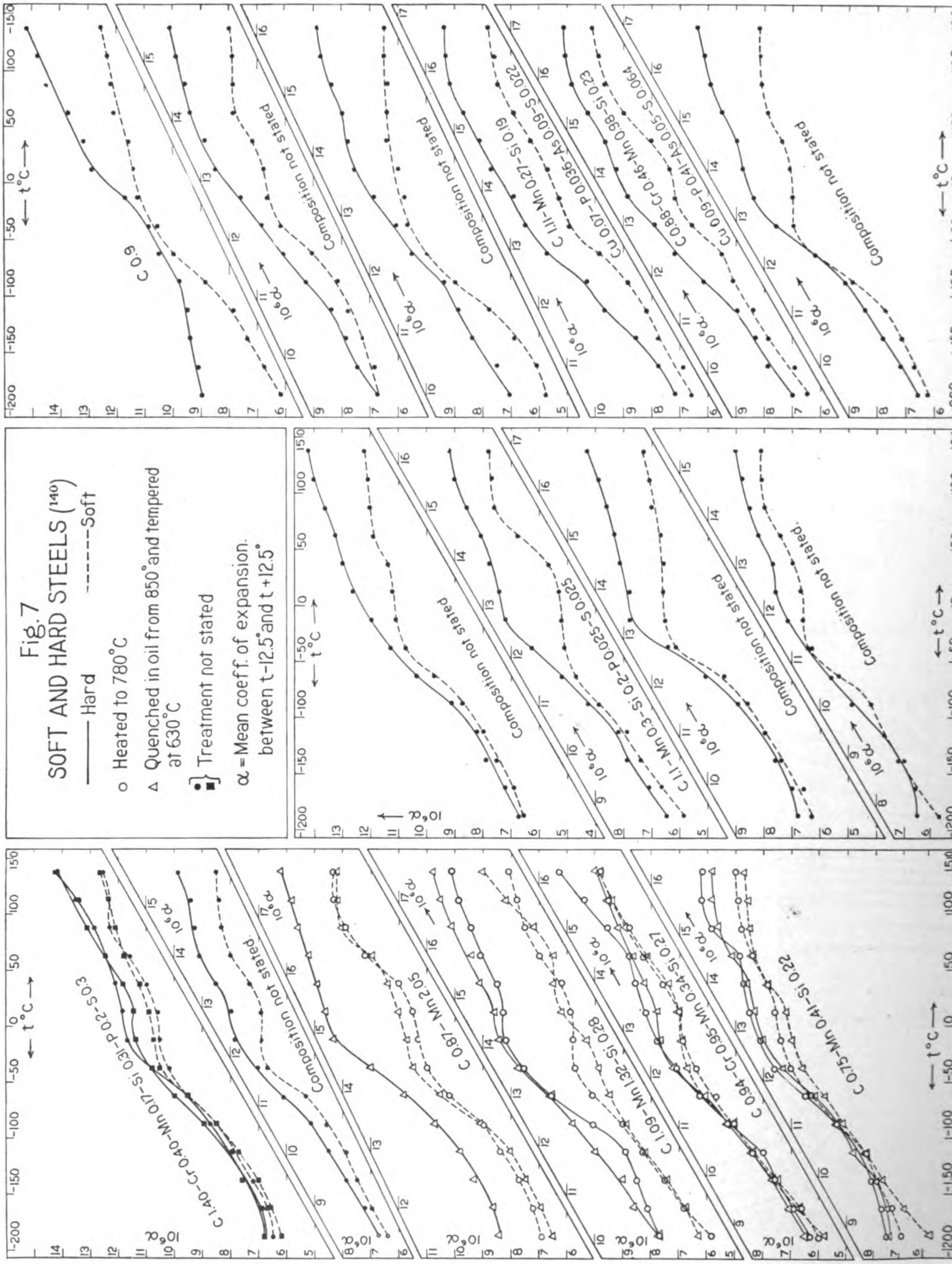


Fig. 7
SOFT AND HARD STEELS [140]

TABLE 4.—GENERAL TABLE.—(*Continued*)

Fe-Mn-C; *v. also* Tables 24 and 31

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Fe with Mn, < 10....	855	800	19.6–23.8		
Fe with Mn, 11.2.....	855	0 to 38	14.97	22.9_β	(81)
Fe with Mn, 14.......	855	0 to 1000	24.5		(84)

Fe-Mo-C; *v. also* Table 30

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Fe with Mo, ≯1.58...	906	100 to 700	11.8–16.3		(77)

Fe-Ni; *v. also* Tables 25, 27 and Figs. 8–13

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Fe with Ni, < 35.....		20 to 900	11.3–16.9		
Fe with Ni, 35–100...		0 to 800	10–18		
Fe with Ni, 36.1; made by Societé Genevoise; *v.* Table 27 ("Invar")	727	−200 to −20	0.25	-4.97_β, -6.13_γ	(137)
		−200	1.53		Comp.*
		−100	1.06		Comp.*
		− 50	0.70		Comp.*
		− 20	0.44		Comp.*
		0 to 100	1.5		(20, 127)
Fe with Ni, 36.1; Mn, 0.39; Cu, 0.39 ("Invar")	727	100 to 200	2.8		(127)
		200 to 250	4.8		(127)
		250 to 300	9.6		(127)
		300 to 400	13.7		(127)
		400 to 500	16.1		(127)
		500 to 600	17.7		(127)
		600 to 700	19.1		(127)
		750	20.3		(127)

* Computed, using above values of α, β, γ.

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Fe with Ni, 31.4....	727	0 to 38	3.395	8.85_β	(58, 63)
Fe with Ni, 34.6....	727	0 to 38	1.373	2.37_β	(58, 63)
Fe with Ni, 35.6....	727	0 to 38	0.877	1.27_β	(58, 63)
Fe with Ni, 37.3....	727	0 to 38	3.457	-6.47_β	(58, 63)
Fe-Ni, 34.8; Cr, 1.5.	727	0 to 38	3.580	-1.32_β	(58, 63)
Fe-Ni, 35.7; Cr, 1.7.	727	0 to 38	3.373	1.65_β	(55, 63)
Fe-Ni, 36.4; Cr, 0.9.	727	0 to 38	4.433	-3.92_β	(55, 63)

Fe-Ni-C; *v.* Tables 25, 26, 27, 28 and Figs. 8–13.
Fe-Ni-Cr-C; *v.* Tables 28, 29.
Fe-Ni-Cr-Mo-C; *v.* Table 29.
Fe-Ni-Si-C; *v.* Table 31.
Fe-Ni-V-C; *v.* Table 28.
Fe-Si; *v.* Table 31.
Fe-V-C; *v.* Table 28.
Fe-X-Y-C (Alloy Steels); *v.* Tables 28, 29, 30.

Fe-W-C; *v. also* Table 30

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Fe with W, 1.7–2.2....	1416	100 to 700	12.0–16.2		(77)

Fe-W-Cr-C; Fe-W-Cr-Mo-C; etc. (High Speed Steels); *v.* Table 30.
Hg-Ag-Sn-Cu-(Zn); *v.* Table 33.

Mn-Si-Fe; *v. also* Table 31

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Mn, 68; Si, 19.55; Fe, 11.6.............		15 to 900	18.27		(2)
Same, Tp 600° Q_w 15°.		15 to 900	16.75		(2)

Mo (Commercial); *v.* Table 34.
Ni (Commercial); *v.* Table 35.

Ni-Cr; *v. also* Fig. 5

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ni, 90; Cr, 10........	190	0 to 1000	12.80	4.33β	(27)
Ni, ≮ 85; Cr, ≯ 15....		0 to 900	12.8–20.8		
Ni, 87; Cr, 9; Fe, 1.5; etc.................	949	0 to 38	12.34	6.02β	(61)
Ni, 85; Cr, 10; Fe, 3; etc.................	949	0 to 38	12.63	8.77β	(61)

Ni-Fe-Cr

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ni, 60; Fe, 26; Cr, 12; C, 0.6; Si, 0.4; Mn, 1.0 (cast)..........	949	20 to 100	12.1		(67)
Ni, 60; Fe, 25; Cr, 12 (D_c)..............	949	20 to 100	11.6		(67)

Ni-Fe-Si; *v.* Table 36.

Ni-Cu-Fe-Mn; *v. also* Table 14

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ni, 67; Cu, 28; (Fe, Mn, Si, etc.) 5; *v.* Table 14	908	25 to 100	13.7–14.5		(129)
		25 to 300	14.9–15.2		(129)
		300 to 600	16.6–18.4		(129)
		25 to 600	15.9–16.7		(129)

TABLE 4.—GENERAL TABLE.—(*Continued*)

Ni-Cu-Fe-Mn.—(*Continued*)

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ni, 66.58; Cu, 29.57; Fe, 1.79; Mn, 1.78; C, 0.15; Si, 0.09; S, 0.03; R_h wire, typical sample	909	0 to 600	13.8	3.375β, 0.83γ	(129)
		0 to 100	14.1		Comp.*
		100 to 200	14.8		Comp.*
		200 to 300	15.6		Comp.*
		300 to 400	16.5		Comp.*
		300 to 600	17.3		Comp.*

* Computed, using above values of α, β, γ.
Ni-Cu-Mn; *v.* Table 14.
Ni-Fe; *v.* Fe-Ni.

Ni-Si; *v. also* Table 36

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Ni, 80.6; Si, 16.2; Fe, 2.5................	1243	15 to 1000	12.20		(2)
Same, Tp 1000° Q_w 15°		15 to 1000	13.37		(2)
Ni, 75; Si, 17.01; Fe, 7.6................	1243	15 to 1000	12.35		(2)
Same, Tp as above....		15 to 1000	13.20		(2)
Ni, 39; Si, 17.86; Fe, 28.3...............	1243	15 to 1000	16.88		(2)
Same, Tp 600° Q_w 15°		15 to 1000	12.39		(2)

Ni-Si-Fe; *v.* Table 36.
Pb-Bi; *v.* Table 38.
Pb-Cd; *v.* Table 38.

Pb-Sn; *v. also* Table 38

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Pb, 100; Sn, 0........		15 to 110	29.3		(113)
Pb, 90.29; Sn, 9.71....		15 to 110	27.9		(113)
Pb, 87.5; Sn, 12.5.....		15 to 110	27.45	$SnPb_4$	(113)
Pb, 81.64; Sn, 18.36...		15 to 110	26.6		(113)
Pb, 71.64; Sn, 28.36...		15 to 110	25.8		(113)
Pb, 61.98; Sn, 38.02...		15 to 110	24.7		(113)
Pb, 52.09; Sn, 47.91...		15 to 110	23.8		(113)
Pb, 42.07; Sn, 57.93...		15 to 110	21.7		(113)
Pb, 32.82; Sn, 67.18...		15 to 110	21.6		(113)
Pb, 30.5; Sn, 69.5.....		15 to 110	21.6	Sn_4Pb	(113)
Pb, 22.53; Sn, 77.47...		15 to 110	21.4		(113)
Pb, 8.72; Sn, 91.28....		15 to 110	20.6		(113)
Pb, 0; Sn, 100		15 to 110	21.8		(113)

Pt-Ir

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Pt, 90; Ir, 10.......		0 to 38	8.651	1.00β	(5, 58)
		0 to 1000	8.841	1.306β	(31)
Pt, 80; Ir, 20.......		−190 to 16	7.502		(65)
		0 to 1000	8.198	1.42β	(74)

Pt-Rh

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Pt, 80; Rh, 20........		0 to 1500	8.79	1.61β	(31)

Sb-Cu; *v.* Cu-Sb and Fig. 3.
Si-Cu; *v.* Cu-Si and Table 15.

Si-Fe (Industrial Ferro-silicon); *v. also* Table 37

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Si, 75; Fe...........		15 to 1000	5.45		(2)
Si, 50; Fe...........		15 to 1000	16.23		(2)
Si, 32; Fe...........		15 to 1000	13.97		(2)
Si, 17.02; Fe.........		15 to 1000	14.45		(2)

Sn-Au; *v.* Table 38.
Sn-Bi; *v.* Table 38.
Sn-Pb; *v.* Pb-Sn; *v. also* Table 38.
Sn-Zn; *v.* Table 38.

Zn-Al; *v. also* Tables 9 and 10, and Fig. 4

% composition	Ind. No.	Range, °C	$10^6\alpha$	$10^9\beta$ and $10^{12}\gamma$	Lit.
Zn, 95; Al, 5 to Zn, 14; Al, 86		20 to 100	24.3–33.3		(70)
		20 to 200	27.3–37.2		(70)
		20 to 300	28.3–40.7		(70)
Zn, 100–0; Al, 0–100		25 to 250	27.1–32.6		(128)
		20 to 250	27.7–38.2		(125)

Zn-Cu; *v.* Fig. 6.

TABLE 5.—AL-CU (70)

% composition					$10^6\alpha_{t_1}^{t_2}$					$100\frac{\Delta l}{l}$ after test
Al	Cu	Si	Fe	Mn	20 to 100°C	20 to 200°C	20 to 300°C	20 to 400°C	20 to 500°C	
95.4	3.75	0.30	0.36	0.18	23.7	24.6	27.2	26.7	27.5	0.02
93.4	5.81	0.36	0.42		23.8	24.9	27.8	27.8	28.0	0.07
91.1	7.68	0.39	0.46	0.33	23.7	26.3	28.0	26.6	27.4	0.05
91.1	7.87	0.33	0.45	0.22	23.4	26.8	28.0	26.6	27.2	0.04
89.2	9.95	0.39	0.44		22.4	24.2	28.3	27.3	27.7	0.11
87.3	11.88	0.39	0.43		22.4	24.1	28.6	27.5	27.6	0.11

Table 6.—Al-Cu-Mg-Si (Duralumin) (70)

Treatment	% composition Al	Cu	Mg	Mn	Fe	Si	$10^6\alpha_{t_1}^{t_2}$ 20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	20 to 400°C	20 to 500°C	$100\frac{\Delta l}{l}$ after test
Sand cast	94.8	3.68	0.36	0.57	0.35	0.25	23.4	24.7	25.7	26.0	26.7	27.5	+0.02
R_b (*ca.* 410°) 3.5 to 0.25 in. thick	94.4	3.74	1.08		0.52	0.30	23.8	24.7	25.3	25.7	26.3	27.2	+0.03
R_c W 520° Q_w V 120°/2 d	94.4	3.74	1.08		0.52	0.30	23.7	25.2	25.8	26.4	27.3	27.3	−0.01
R_d (contains 0.20 % Ca)	94.6	3.66	0.52	0.51	0.37	0.16	23.1	26.0	26.6	26.8			+0.06
Same, reheated							22.3	24.0	24.4	25.0	25.9	25.7	+0.02
Same, Tp 500°, Q	94.6	3.66	0.52	0.51	0.37	0.16	23.2	24.1	25.3	26.0			+0.03
Same, reheated and quenched							22.2	23.5	24.3	25.1	26.1	26.6	+0.05

Table 7.—Al-Cu-Mn; Al-Cu-Si; Al-Mn; Al-Mn-Cu; Al-Si-Cu; Al-Si-Cu-Mn (70)

% composition Al	Mn	Cu	Si	Fe	$10^6\alpha_{t_1}^{t_2}$ 20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	20 to 400°C	20 to 500°C
97.8	1.05	0.19	0.41	0.57	23.7	25.6	26.0	25.7	26.3	27.4; 28.5*
96.7	1.80	0.23	0.40	0.84	23.1	24.3	24.9	25.6	26.1	27.2; 27.9*
96.2	1.08	1.91	0.30	0.51	23.6	25.2	26.7	26.9	26.8	27.5
93.9	0.01	2.20	3.33	0.55	23.4	23.9	24.2	24.4		
89.6		2.43	7.42	0.53	21.7	22.5	23.0	23.4		
87.1		2.33	9.96	0.60	20.7	21.7	22.2	22.7		
91.3		4.41	3.75	0.57	22.4	23.4	23.8	24.1		
88.3		4.53	6.61	0.57	21.5	22.3	22.8	23.1		
88.7		6.62	4.08	0.64	21.8	22.9	23.4	23.6		
83.7		6.29	9.45	0.53	20.6	21.6	22.0	22.2		
84.6		4.58	10.28	0.54	20.4	21.3	21.8	22.1		
93.0	0.93	2.40	3.12	0.55	22.2	23.4	23.7	23.8		
86.4	0.82	2.32	9.97	0.50	20.4	21.5	22.0	22.4		
85.8	0.89	2.49	10.22	0.56	20.8	21.5	22.0	22.3		
85.6	1.17	2.47	10.18	0.70	20.4	21.5	22.0	22.3		

* 20 to 600°.

Table 8.—Al-Si (70)

% composition Al	Si	Fe	Cu	$10^6\alpha_{t_1}^{t_2}$ 20 to 100°C	20 to 200°C	20 to 300°C	20 to 400°C	20 to 500°C	300 to 600°C	$100\frac{\Delta l}{l}$ after test
95.0	4.15	0.52	0.33	22.2	23.2	24.1				−0.01
92.0	7.28	0.47	0.27	21.8	22.8	23.5				0.00
89.5	9.81	0.50	0.22	21.1	21.9	22.9				0.00
86.8	12.55	0.56	0.08	19.4	21.2	24.6	24.5	24.4	24.3	+0.09
				21.1*	21.7	22.4	22.9	23.0	23.9	+0.02
86.8†	12.55	0.56	0.08	19.5	20.5	22.2	22.9	23.0	24.1	−0.01

* The values in this horizontal row were obtained on a second heating.

† This alloy, containing 86.81 % Al, etc., is modified by the addition, just before casting, of 0.1 % metallic sodium, in accordance with the process described by J. D. Edwards in U. S. Patent No. 1 410 461.

Table 9.—Al-Zn (70)

% composition Al	Zn	Cu	Si	Fe	Mn	$10^6\alpha_{t_1}^{t_2}$ 20 to 100°C	20 to 200°C	20 to 250°C	20 to 300°C	$100\frac{\Delta l}{l}$ after test
85.83	12.17	1.47	0.21	0.31	0.01	24.3	28.1	28.3	27.9*	+0.01
						25.5	27.3	28.5	28.3	
22.57	77.22	0.05	0.05	0.11	Nil	27.5	29.6			+0.02
						26.0†	28.3	30.5		−0.01
5.29	94.66	0.02	0.01	0.02	Nil	33.3	35.7			+0.02
						32.0†	37.2	40.7		+0.02

* From 20 to 400°, $10^6\alpha$ is 27.6; from 20 to 500°, $10^6\alpha$ is 28.6.

† The values given in this horizontal row were obtained on a second heating.

Table 10.—Al-Zn; $10^6\alpha_{t_1}^{t_2}$, between 20 and t°C (125)

Al-Zn alloys having 37.5–87.5 % Zn exhibit anomalous expansion above 250°C. The italicized values indicate results obtained on cooling, where different from those on heating.

$$\left.\begin{array}{l}\text{For } 100\%\ \text{Al},\ \alpha_t = (23.0 + 0.014t)\ 10^{-6} \\ \text{For } 100\%\ \text{Zn},\ \alpha_t = (35.4 + 0.020t)\ 10^{-6}\end{array}\right\}\ cf.\ \text{Table 1.}$$

Table 10.—Al-Zn; $10^6\alpha_{t_1}^{t_2}$, between 20 and t°C (125) (*Continued*)

t,°C \ % Zn	0	12.5	25	37.5	50	62.5	75	87.5	100
100	23.6	23.9	26.1	26.6	26.5	26.1	27.1	26.4	36.4
200	24.5	24.8	27.0	27.5	27.6	27.4	28.5	29.1	37.6
230			27.6				29.6		
240			27.6				29.7		
250		27.7	27.7	28.9	29.3	29.8	30.4	30.7	38.2
		27.6		*30.1*	*30.8*	*30.0*	*38.0*		
260				29.0	29.4	30.1			38.3
264				30.6	33.4				
266								31.5	
								36.9	
270			27.7	29.0	30.3	30.7	30.6	31.5	38.3
				30.8	*33.9*	*36.7*	*38.5*	*38.0*	
280			27.8	29.5	33.3	31.6	37.3	32.4	38.5
			27.7	*30.9*	*33.8*	*36.7*	*38.6*		
285								37.9	
290			27.8		33.6	36.8	39.0	38.7	38.5
300	25.2	25.9	28.0	30.3	33.7	36.5	39.0		38.6
400	25.9	27.1	29.1						

Table 11.—C (Graphite)

The most reliable determinations of the expansion of graphite give results differing widely, probably owing to the differences in physical condition of the specimens used in the determinations.

Description of sample	Composition and treatment	Range, °C	$10^6\alpha$	$10^9\beta$	Lit.
Electric-arc carbon from H. Moissan.	99.97 % C $d_4^{18} = 2.216$ after being compressed to (5–10)10^3 kg/cm²	−163 to −38	7.2		(29)
		− 38 to 18	2.7		
Acheson graphite		0 to 1500	0.55	1.6	(33)
	Longitudinal	0 to 400	2.4*		(71.1)
	Transverse	0 to 400	3.5*		(71.1)
Earlier determinations:					
Batongol graphite		10 to 90	7.5	5	(50)
Siberian graphite	98 % C, d = 1.8	20 to 300	3.8		(99)

* Partial report on research in progress (1926).

Table 12.—Co-Cr-W-C (Stellite) (129)

No.*	Approximate composition, % Co-Cr-W	$10^6\alpha_{t_1}^{t_2}$ 20 to 100° C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	20 to 300°C	300 to 600°C	20 to 600°C
1	80–20	14.1	15.1	16.2	15.9	16.0	18.9	15.2	16.9	16.1
2	55–40–3†	13.4	15.2	16.0	16.3	17.5	20.2	15.0	18.0	16.3
3	55–40–3†	12.2	13.1	14.0	14.3	15.4	17.9	13.2	15.8	14.6
4	55–35–10	11.0	12.3	13.6	13.8	13.3	16.9	12.4	14.7	13.6
4	55–35–10	Between −94 and +19°C, $\alpha_{t_2}^{t_1} = 10.2 \times 10^{-6}$								

* Description: 1. Soft, malleable. 2. Hard, malleable. 3. Hard malleable, hammered. 4. Stellite No. 2.

† Alloy contains 2 % C.

TABLE 13.—Cr-Fe-C-Si AND Cr-Fe-Si-C (2)

Composition and treatment	No. / Range, °C	$10^6\alpha_{t_1}^{t_2}$ 1	2	2a	3	3a	4	4a
1. Industrial Cr, 48; Fe, 30; Si, 17; C, 5	15 to 100	10.23	8.00	9.17	7.52	9.29	7.52	7.17
2. Industrial Cr, 47.6; Fe, 47.1; C, 2.84; Si, 2.2	100 to 200	8.89	8.49	8.68	7.79	7.88	6.49	6.28
2a. Same Tp at 1000° in H_2O at 15°C	200 to 300	9.58	8.38	9.18	7.68	8.58	7.29	6.88
3. Industrial Fe, 46.5; Cr, 45.9; C, 6.67; Si, 0.95	300 to 400	11.17	10.07	9.87	10.37	9.87	8.18	8.38
3a. Same Tp at 1000° in H_2O at 15°C	400 to 500	11.85	11.36	11.95	10.06	9.46	9.37	9.37
4. Cr, 53.3; Fe, 39.1; C, 6.21; Si, 0.93	500 to 600	12.43	11.94	10.94	10.55	9.75	10.46	8.96
4a. Same Tp at 1000° in H_2O at 15°C	600 to 700	12.91	12.82	13.42	11.83	10.74	10.94	8.16
	700 to 800	13.49	13.30	12.90	11.92	10.42	11.43	10.24
	800 to 900	13.18	11.80	10.31	11.21	8.93	10.12	8.63
	900 to 1000	13.46	11.58	11.78	11.89	8.82	11.10	9.82
	15 to 1000	11.75	10.62	10.86	10.12	9.39	9.32	8.41

TABLE 14.—Ni-Cu-Fe-Mn (MONEL METAL) (129)

% composition Ni	Cu	Fe	Mn	C	Si	S	Pb	Treatment	$10^6\alpha_{t_1}^{t_2}$ 25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C
60.05	32.46	2.21	2.00	0.15	0.87	0.035	2.22	Cast	13.9	15.0	15.8	16.8	17.7	20.6
								Heated to 900°C	14.3	15.0	15.7	16.7	18.1	18.3
66.18	28.42	2.37	2.10	0.18	0.70	0.038		Cast	13.7	15.1	15.7	16.6	17.7	18.5
								Heated to 900°C and cooled slowly	13.9	15.0	15.7	16.6	17.8	18.7
66.58	29.57	1.79	1.78	0.15	0.09	0.030		Hot rolled	14.2	14.9	15.5	16.7	17.0	18.1
								Same, heated to 870°C	14.3	15.3	15.8	16.5	17.4	17.7
67.32	28.73	1.74	1.66	0.31	0.19	0.035		Hot rolled	14.5	15.1	15.9	16.4	17.1	16.2
								Same, heated to 900°C	14.3	15.0	15.8	16.5	17.4	17.7
68.87	29.03	1.60	0.18	0.13	0.15	0.027		Hot rolled	14.2	14.7	15.6	16.4	17.6	17.9
								Same, heated to 870°C	14.0	15.0	15.9	16.4	17.3	18.1

TABLE 15.—Cu-Si; Cu-Si-Fe (2)

% composition and treatment	No. / Range, °C	$10^6\alpha_{t_1}^{t_2}$ 1	2	3	4	5
1. Cu, 93.5; Si, 3.3; Fe, 2.6	15 to 100	15.41	10.58	12.10	14.94	6.58
2. Cu, 89.6; Si, 6.17; Fe, 3.7	100 to 200	12.19	12.88	15.08	14.28	4.49
3. Same Tp at 780°C	200 to 300	14.07	14.56	17.15	15.46	4.39
4. Cu-Si with Si, 10	300 to 400	14.65	18.83	18.52	16.73	4.39
5. Cu-Si with Si, 55	400 to 500	17.71	21.18	20.77	19.38	4.09
	500 to 600	20.46	21.83	19.93	15.57	3.79

TABLE 15.—Cu-Si; Cu-Si-Fe (2).—(*Continued*)

% composition and treatment	No. / Range, °C	$10^6\alpha_{t_1}^{t_2}$ 1	2	3	4	5
	600 to 700	20.72	21.88	20.29	15.85	5.88
1. Cu, 93.5; Si, 3.3; Fe, 2.6	700 to 800	21.86	20.15	22.03	32.94	4.18
2. Cu, 89.6; Si, 6.17; Fe, 3.7	800 to 900	23.19	17.55	19.51		1.09
3. Same Tp at 780°C	900 to 1000					0.09
4. Cu-Si with Si, 10	15 to 1000					3.87
5. Cu-Si with Si, 55	15 to 900	17.88	17.83	18.49		
	15 to 700				16.08	

TABLE 16.—Cu-Zn (COLD ROLLED BRASSES) (69)

Metallurgical subdivision	Ind. No.	% composition Cu	Zn	Sn	Pb	Fe	Range, °C	$10^6\alpha$	$10^9\beta$	$10^6\alpha_t$ at 50°	100°	150°	200°	250°
α-Brass	1134	97.0	2.97		0.01	0.02	−49 to 301	16.48	3.63	16.84	17.21	17.57	17.93	18.30
	620	94.9	5.11		.01	.01	28 to 305	16.81	3.89	17.20	17.59	17.98	18.37	18.76
	401	90.3	9.70		.01	.03	26 to 302	17.01	3.79	17.39	17.77	18.15	18.53	18.90
	1182	85.2	14.76		.01	.02	−50 to 300	17.03	5.12	17.54	18.05	18.57	19.08	19.59
	799	80.0	19.89		.05	.03	28 to 302	17.22	5.90	17.81	18.40	18.99	19.58	20.17
	301	75.3	24.64		.02	.03	28 to 300	17.58	6.24	18.20	18.83	19.45	20.08	20.70
	1316	72.0	27.95		.01	.02	25 to 306	17.73	6.52	18.38	19.03	19.69	20.34	20.99
	336	70.3	29.66		.03	.03	19 to 301	17.75	6.53	18.40	19.06	19.71	20.36	21.02
αβ-Brass	339	66.5	33.43	By difference	.04	.03	−50 to 301	18.26	5.61	18.82	19.38	19.94	20.50	21.06
		64.8	34.92		.24	.03	20 to 299	18.15	6.45	18.80	19.44	20.08	20.73	21.38
	400	63.6	36.17		.17	.03	21 to 299	18.11	7.25	18.84	19.56	20.28	21.01	21.74
	1409	62.1	37.71		.17	.02	23 to 308	18.05	8.55	18.90	19.76	20.62	21.47	22.32
Leaded brass α or αβ	778	88.3	10.00		1.68	.02	21 to 301	17.06	3.89	17.45	17.84	18.23	18.62	19.00
	780	78.3	20.01		1.68	.03	22 to 301	17.48	5.24	18.00	18.53	19.05	19.58	20.10
	782	68.7	29.67		1.65	.03	20 to 304	17.91	6.52	18.56	19.21	19.87	20.52	21.17
	604	62.3	35.04		2.57	.06	21 to 302	18.26	6.56	18.92	19.57	20.03	20.88	21.54
α-Brass containing Sn	600	81.7	17.94	0.31	0.04	0.01	19 to 301	17.31	5.80	17.89	18.47	19.05	19.63	20.21
	16	70.6	28.21	1.10	.04	.01	20 to 301	17.94	6.93	18.63	19.33	20.02	20.71	21.40

Table 17.—Cu-Zn (Muntz Metal Type) (96)

% composition					$10^6\alpha_{t_1}^{t_2}$					
Cu*	Zn	Sn	Pb	Fe	20 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 450°C	500 to 600°C
65.6A	32.9	1.3	0.2	0.1	19.2	20.0	22.0	22.5	23.5	24.5
54.5B	43.9	1.3	0.1	0.2	21.6	21.8	22.8	29.6	35.0	30.5
54.7B	44.5	0.7	0.1	0.1	22.8	19.4	23.5	27.5	39.2	26.9
65.3A	34.5	0.23	0.2	Tr.	18.7	20.0	22.0	22.5	23.0	23.7
64.6A	35.4	0.06	0.04	<0.04	22.8	22.2	21.9	22.2	23.4	23.6
55.5B	44.5	0.07	0.05	<0.04	20.0	21.0	23.6	28.0	35.0	27.0

The transformation point, at which abnormal expansion of these brasses occurs, is about 460°C.

* A = α-Brass; B = β-Brass.

Table 18.—Fe-C (Ingot Iron, Cast Iron and C-Steel) (37)

% composition							Ind. No.	$10^6\alpha_{t_1}^{t_2}$				
C	Si	P	Mn	S	Ni + Co	Cu		0 to 250°C	0 to 375°C	0 to 500°C	0 to 625°C	0 to 750°C
0.14	0.07	0.42	0.44	0.03	0.53		1341	12.84	13.41	13.99		14.74
0.16		0.25	0.61	0.05	0.03	0.07	724	12.72	13.53	14.05		14.70
0.55	0.31	0.44	0.60	0.05	0.54		889*	12.48	13.17	13.79	14.37	13.29
3.22	1.68	0.46	0.71	0.08	0.48		661	11.18	11.98	12.58	13.93	
3.19	1.67	0.32	0.64	0.10	0.10	0.16	661	11.30	12.21	12.80		
3.59	1.18	0.04	0.46	0.06	0.04	0.13	661	11.34	12.12	12.88	13.35	14.22
										0 to 875°C = 14.93		

* Cast.

Table 19.—Fe-C (C Steels) (41)

Percentage Composition of Alloys

Sample	C	Mn	Si	P	S	Cu	Sample	C	Mn	Si	P	S	Cu
A	0.05–0.06	0.08	Tr.	Tr.	0.023	0.03	I	1.25	0.12	0.07	Tr.	0.019	0.02
B	0.09	0.08	0.02	0.01	0.01	0.01	J	1.45	0.14	0.10	0.01	0.013	0.04
C	0.22	0.12	0.01	0.01	0.03	0.04	K	1.67	0.17	0.11	0.01	0.013	0.04
D	0.33	0.12	0.03	0.01	0.03	0.03	L	1.97	0.15	0.08	Tr.	0.015	Tr.
E	0.40	0.11	0.07	0.01	0.03	0.03	M	2.24	0.15	0.08	Tr.	0.015	Tr.
F	0.56	0.09	0.04	Tr.	0.023	0.02	N	3.66	0.14	0.09	0.015	0.012	Tr.
G	0.65	0.12	0.09	0.01	0.03	0.03	O	3.80	0.16	0.05	0.015	0.01	Tr.
H	0.81	0.10	0.06	Tr.	0.025	0.02							

Values of $10^6\alpha_{t_1}^{t_2}$

Range, °C \ Sample	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
20 to 50	11.49	11.16	11.22	10.92	10.73	10.17	10.74	10.17	10.58	9.67	10.02	9.72	9.03	8.57	8.43
20 to 100	11.66	11.58	11.66	11.09	11.29	10.98	11.04	11.04	10.87	10.13	10.44	9.94	9.61	8.59	8.71
20 to 150	12.06	12.06	11.96	11.70	11.45	11.44	11.34	11.43	11.14	10.38	10.51	10.02		8.75	8.76
20 to 200	12.32	12.61	12.12	11.89	11.99	11.85	11.57	11.56	11.08	10.58	10.28	9.96	9.64	8.83	8.49
20 to 250	12.56	12.72	12.49	12.38	12.07	12.27	11.88	11.93	11.46	11.16	10.83	10.52	10.25	9.04	9.35
20 to 300	13.02	13.01	12.78	12.72	12.47	12.65	12.31	12.43	11.87	11.67	11.38	11.14	10.96	9.88	10.11
20 to 350	13.34	13.36	13.12	13.09	12.86	13.08	12.74	12.84	12.33	12.18	11.88	11.72	11.59	10.63	10.92
20 to 400	13.65	13.63	13.38	13.42	13.26	13.40	13.16	13.21	12.75	12.68	12.34	12.21	12.15	11.35	11.52
20 to 450	13.98	13.93	13.68	13.88	13.66	13.74	13.42	13.55	13.16	13.13	12.82	12.68	12.72	11.96	12.12
20 to 500	14.22	14.18	13.93	14.02	13.90	14.02	13.84	13.82	13.36	13.48	13.15	13.12	13.16	12.50	12.62
20 to 550	14.33	14.38	14.17	14.20	14.17	14.27	13.93	14.08	13.78	13.78	13.38			12.91	
20 to 600	14.64	14.64	14.38	14.43	14.36	14.50	14.20	14.22	13.99	14.04	13.66			13.23	
20 to 650	14.85	14.86	14.66	14.59	14.61	14.67	14.52	14.50	14.22	14.24	13.93			13.70	
20 to 700	15.01	15.03	14.81	14.76	14.76	14.81	14.65	14.67	14.41	14.42	14.24			13.92	
20 to 750	14.84	14.93													
20 to 800	14.67	14.61	12.93	11.33	11.72	12.46	12.68	14.22	14.78	15.13	15.02			14.13	
20 to 900	13.14	12.34	12.48	11.53	12.35	13.54	13.87	15.05	16.64	17.63	17.57			15.04	
20 to 1000	13.35	13.32	13.16	13.08	13.25	14.38	14.76	15.70	17.43	19.50	19.61			15.86	
700 to 1000	9.50	9.42	9.40	9.29	9.91	13.47	15.00	17.90	24.10	29.74	31.45			20.24	

Table 20.—Fe-C (C-Steel Rails) (18)

Bessemer rails			Open hearth rails		
% composition	$10^6\alpha_0^t$	t,°C	% composition	$10^6\alpha_0^t$	t,°C
C, 0.50 –0.39	14.2	500	C, 0.66 -0.70	14.4	500
S, 0.042–0.071	15.0	600	S, 0.033–0.057	14.7	600
P, 0.081–0.067	15.2	700	P, 0.028–0.025	14.9	700
Mn, 0.93 –0.90	13.3	800	Mn, 0.66 –0.72	14.3	800
Si, 0.101–0.035	14.0	900	Si, 0.160–0.079	15.0	900
Cu, 0.007–0.105	14.6	1000	Cu, 0.016–0.026	15.7	1000
Ni, 0.06 –0.12	15.1	1100	Ni, 0.00	16.2	1100
Cr, 0.00 –0.17			Cr, 0.01		

Abnormal expansion occurs between 700 and 800°C.

Table 21.—Fe-Cr-C (94)

Containing 0.6% C

% Cr	Transformation temp., °C	$10^6\alpha_{100}$	$10^6\alpha_{500}$
0	790	11.5	15.9
0.5	785	11.9	15.6
1	777	11.3	14.8
2	787	11.8	14.3
3	802	12.1	14.8
5	830	11.0	13.9
10	837	10.1	13.1
20	845	10.0	12.0

TABLE 22.—FE-CR-C (STAINLESS STEEL) [129]

Range, °C	$10^6\alpha_{t_1}^{t_2}$ Hard	$10^6\alpha_{t_1}^{t_2}$ Annealed	Composition
20 to 100	9.6	10.3	Cr, 13.1
20 to 200	9.8	10.7	C, 0.3
200 to 400	9.9	12.3	Mn, 0.18
400 to 600	13.8	13.3	Si, 0.11
600 to 800	13.4	13.6	P, 0.02
20 to 600	11.2	12.1	S, 0.011

Abnormal expansion occurs between 825 and 855°C. The hardened steel also exhibits irregular expansion between 200 and 400°C.

TABLE 23.—FE-MN-C (KRUPP'S CARBON STEELS) [77]

% composition C	% composition Mn	$10^6\alpha_{15}^{75}$
0.14	0.39	11.88
0.18	0.34	12.11
0.31	0.65	11.73
0.44	0.67	11.65
0.56	0.30	12.08
0.64	0.27	11.79
0.75	0.35	11.55
0.80	0.30	11.70
0.94	0.35	11.50
1.02	0.36	11.49
1.30	0.40	10.94
1.50	0.36	10.83

TABLE 24.—FE-MN-C (MN STEELS) [93]

% Mn	α_{100} Pearlitic or martensitic	α_{100} Austenito-martensitic	α_{500} Pearlitic or martensitic	α_{500} Austenito-martensitic	α_{800} Austenitic
0.11	12.6		15.4		19.9
0.31	12.3		14.8		19.6
0.6	11.5		14.8		20.1
0.8	11.6		14.7		19.6
1.1	11.8		15.2		20.4
1.6	12.8		15.3		21.0
2.0	13.4		15.7		21.2
3.0	13.5		15.7		21.9
5.0	12.9		15.5		22.6
6.9	12.5		15.6		23.5
7.9		14.7		18.0	23.5
8.8		16.2		21.9	23.4
9.8	12.0	16.8	15.8	22.0	23.8

Anomalous expansion of these Mn steels begins at about 650°C.

TABLE 25.—FE-NI-C (NI STEELS INCLUDING INVAR)

t,°C \ % Ni	$10^6\alpha_0^t$ [87] 5	25	33	$10^6\alpha_t$ [82] % Ni	$10^6\alpha_{20}$
50	9.44	14.72	−0.18	0	11.0
100	10.03	15.86	+0.09	10	13.0
150	10.59	16.75	0.80	20	19.5
200	11.01	17.40	1.93	30	12.0
250	11.33	17.81	3.50	36	0.9
300	11.55	17.98	5.50	40	6.0
				50	9.7
				80	12.5
				100	12.8

TABLE 26.—FE-NI-C (NICKEL STEELS CONTAINING 0.9% C) [134]

% Ni	$10^6\alpha_{t_1}^{t_2}$ 20 to 100°C	20 to 300°C	20 to 500°C	20 to 700°C	20 to 900°C
3	13	11.1	10.7	11.1	11.4
4	12	11.1	10.5	10.5	11.3
6	11	11.8	10.8	8.2	13.7
10	9	9.6	9.3	7.1	12.9
12	8	8.5	8.2	7.7	14.2
15	8	9.3	9.0	8.6	14.6
20	8	10.4	9.4	8.8	14.4
25	11	11.2	10.6	8.5	13.6
30	9	12.4	9.4	11.4	14.8
35	1.2	7.7	12.0	13.8	16.9

TABLE 27.—FE-NI-C (INVAR STEELS) [58,63]

% Ni	Range, °C	$10^6\alpha_t = a + bt$ a	b
30.4	0 to 110	4.570	0.0235
	110 to 164	− 4.29	0.104
	164 to 220	11.3	0.008
31.4	0 to 122	3.395	0.015
	122 to 182	−10.37	0.128
	182 to 220	6.44	0.036
34.6	0 to 142	1.373	0.0047
	142 to 220	− 7.18	0.065
37.3	0 to 150	3.457	−0.0072
	150 to 220	0.72	0.011

Table 28. *See* p. 472.

TABLE 28*A*.—STEEL AND IRONS OF TABLE 28 ABOVE THE CRITICAL REGION [130]

No.	$10^6\alpha_{t_1}^{t_2}$ Heating	Temp. range, °C	Cooling	Temp. range, °C	Increase in length at 25°C, μ/m
1	23.4	825 to 900	22.7	900 to 725	−1202
2			22.7	900 to 700	− 462
3	22.7	800 to 900	22.7	900 to 800	− 110
4	22.8	800 to 900	22.8	900 to 800	− 82
5	24.0	800 to 900	23.1	900 to 725	− 400
6	24.1	825 to 900	22.8	900 to 800	− 270
7	24.0	825 to 900	22.6	900 to 800	− 90
8			22.3	900 to 550	− 680
9			21.9	900 to 800	− 198
10			22.0	900 to 805	+ 343
11			23.0	895 to 820	− 593
12					+ 98
13					+ 346
14	22.2	800 to 900	22.8	900 to 700	− 727
15					+ 335
16					+ 18
17			22.7	900 to 800	− 200
18	22.6	800 to 900	21.1	900 to 600	− 920
19	23.0	800 to 900	23.0	900 to 800	− 148
20					− 63
21	22.6	800 to 900	23.1	900 to 800	− 366
22	23.4	906 to 945	23.4	945 to 917	− 120
23	34.0	750 to 875	28.6	875 to 713	
24	23.4	833 to 950	21.6	950 to 760	− 430
25	37.0	815 to 900	25.0	900 to 775	+9040
27					0

TABLE 28.—FE-C; FE-CR-C; FE-NI-C; FE-SI-C; FE-V-C (CARBON AND ALLOY STEELS, CAST IRON AND ELECTROLYTIC IRON) (130)

No.	% composition									$10^6\alpha_{t_1}^{t_2}$									
	C	Mn	P	S	Si	Cr	V	Ni	Miscellaneous	25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	600 to 700°C	25 to 300°C	300 to 600°C	25 to 600°C
1	0.35	1.42	0.013	0.057	0.20	1.00	0.11			12.4	12.8	14.4	15.1	15.9	15.9	16.2	13.3	15.6	14.5
2	0.49	1.21	0.05	0.050	0.12					11.3	12.2	14.2	16.3	17.7	15.4	16.7	12.7	16.5	14.7
3	0.41	0.64	0.052	0.061	0.086					11.1	12.2	14.3	15.8	15.7	16.0	16.6	12.7	15.8	14.3
4	0.44	0.57	0.013	0.033	0.161		0.14			11.2	12.4	14.3	15.4	16.4	16.5	16.8	12.7	16.1	14.5
5	0.59	0.92	0.024	0.033	0.25					11.1	12.5	14.6	15.4	16.1	16.8	16.6	12.9	16.1	14.6
6	0.35	0.08	0.010	0.027	0.110	1.17	0.14			11.0	12.3	14.8	15.6	15.9	16.5	16.2	12.9	16.0	14.5
7	0.36	0.46	0.011	0.029	0.09	0.57	0.12			11.8	12.6	14.4	15.1	16.0	16.6	16.8	13.1	15.9	14.5
8	0.168	0.01	0.010	0.026	0.135	2.50	0.39	3.94		10.8	11.7	13.5	14.0	14.5	14.4		12.1	14.3	13.3
9	0.410	1.11	0.053	0.049	0.115			2.00		11.6	11.9	14.0	16.2	15.7	16.5	16.4	12.6	16.1	14.4
10	0.144	0.10	0.03	0.035	0.034	1.15	0.21		Cu, 1.85	11.2	12.6	13.8	15.6	15.6	16.0	16.7	12.7	15.7	14.3
11	0.252	0.06	0.012	0.035	0.007					11.1	12.0	14.2	15.5	15.9	16.6	16.9	12.5	16.0	14.3
12	0.168	0.08	0.010	0.029	0.038	0.92	0.24		Mo, 0.64	11.3	11.8	13.9	15.3	15.7	16.6	16.1	12.5	15.9	14.2
13	0.122	0.05	0.020	0.040	0.846	0.85	0.23			11.6	12.5	13.7	14.6	15.2	16.0	15.8	12.7	15.2	14.0
14	0.326	0.78	0.014	0.035	0.094			3.59		10.9	11.5	13.6	15.2	15.1	15.7		12.1	15.3	13.8
15	0.342	0.28	0.01	0.043	0.094	0.82	0.26		Cu, 2.70	11.6	12.6	14.2	16.0	15.9	16.4	16.9	12.9	16.1	14.6
16	0.396	0.25	0.012	0.023	0.095				W, 3.96	11.1	12.0	14.0	15.1	15.7	16.4	16.5	12.5	15.7	14.2
17	0.380	1.17	0.055	0.067	0.10			0.81		11.2	12.7	14.3	15.2	16.2	16.7	16.4	12.9	16.1	14.5
18	0.388	1.21	0.010	0.043	1.04			3.67		11.6	12.0	13.2	14.2	15.2	15.6		12.3	15.0	13.7
19	0.512	0.42	0.016	0.021	1.45				W, 1.58	10.4	12.1	13.7	15.9	15.7	16.1		12.2	15.9	14.2
20	0.30–0.40					13.00				10.0	10.6	12.0	12.6	13.5	13.9	13.7	11.0	13.3	12.2
21	0.418	0.68	0.012	0.025	0.23					9.4	12.0	14.3	15.3	16.4	17.1	16.8	12.1	16.2	14.3
22*	0.02	Nil	Nil	0.007	0.006	(Co, Cu, Ni, total 0.014)				12.0	13.0	14.5	15.3	15.9	16.8	17.4	13.3	15.9	14.7
23	1.28	0.37				0.19				11.0	11.6	13.6	15.1	16.3	16.1	17.0	12.0	15.9	14.1
24	0.20	1.10	0.05	0.05		0.5		0.5		12.3	12.9	14.2	15.9	16.2	16.5	16.8	13.2	16.5	14.9
25	3.08				1.68					8.4	11.7	14.2	15.6	14.3	Growing		11.6	Growing	
26	0.14							34.52		3.7	8.4	14.1	16.6	18.4	18.8	19.1	9.2	18.2	13.6
27	0.09	0.19			3.70	0.176	0.005–	0.05–		11.1	12.4	13.3	14.0	15.6	16.0	16.9	12.6	15.3	14.0

* Vacuum electrolytic iron.

TABLE 29.—FE-CR-C; FE-CR-V-C; FE-NI-CR-C (ALLOY STEELS) (92)

% composition							$10^6\alpha_{t_1}^{t_2}$	
C	Si	Mn	P	S	Cr	Ni	25 to 100°C	25 to 270°C
0.34	0.10	0.64	0.012	0.023	0.76	3.43	11.37	12.49
0.30*	0.11	0.66	0.025	0.005	0.86	3.05	11.67	12.57
0.50	0.15	0.64	0.015	0.031	0.88	1.90	11.72	12.70
0.32†	0.23	0.53	0.013	0.015	1.37	3.53	11.83	12.78
0.35	0.0	0.65	0.008	0.045	0.80	3.14	11.73	12.79
0.43	0.0	0.78	0.015	0.027	0.75	1.87	12.00	12.87
0.43‡	0.18	0.81	0.031	0.032	0.88	2.55	11.65	12.89
0.40§‖	0.14	0.76	0.006	0.012	1.20		11.60	13.04
0.34‖¶	0.17	0.72	0.009	0.010	0.96		11.76	13.10
0.44**	2.07	0.81	0.012	0.010			12.52	13.51
0.40††	0.57	0.78	0.011	0.015	0.78		12.76	13.83

* Contains 0.53 % Mo.
† 830° Q_o Tp 570°.
‡ Contains 0.07 % V.
§ 930° Q_o Tp 650°.
‖ Contains 0.17 % V.
¶ 930° Q_o Tp 620°.
** 930° Q_o Tp 590°.
†† 830° Q_o Tp 590°.

TABLE 32.—AG-HG-ZN (131)

Ag-Zn amalgam

% Ag	% Zn	$10^6\alpha_{20}^{50}$	% Ag	% Zn	$10^6\alpha_{20}^{50}$
68	0	25.4	67	2	28.0
68	1	25.9	60	5	24.5
67	1	26.4	54	0	23.4

TABLE 33.—HG-AG-SN-CU-(ZN), AG-SN-CU AMALGAMS (54)

Composition of amalgam alloys						Alloy	Hg-alloy ratio	$10^6\alpha_{37.5}$
	A	B	C	D	E			
Ag......	68	68	70	70	54	B	2.00	25.2–26.8
Sn......	27	26	27	27	30	B	1.60	24.8–25.2
Cu.....	5	5	3	3	16	D	2.00	27.7
Zn......	0	1	0	1	0	C	2.00	27.8–28.5
Total..	100	100	100	101	100	A	1.60	26.0–29.3
						E	1.60	24.3–26.8

Alloy D was made by the addition of 1% Zn to the alloy of composition C.

TABLE 30.—FE-MO-C; FE-W-C; FE-W-CR-C (ALLOY STEELS) (77)

% composition									Ind. No.	$10^6\alpha_t$ at						
C	Si	Mn	P	S	Cr	W	Mo	V		100°C	200°C	300°C	400°C	500°C	600°C	700°C
0.82	0.18	0.26	0.003	0.016	3.71	14.63	0.17	0.20	285	10.0	11.6	12.5	13.2	13.75	14.2	14.4
.47	.56	.16	.014		1.03	1.17			748	11.5	12.3	13.2	14.25	15.25	16.4	17.75
.64	.05	.01	.015	.012	3.73	14.06		0.11	942	11.1	11.9	12.6	13.2	13.65	13.9	14.0
.66	.08	.08	.018	.016	3.43	16.81		0.11	1435		10.8	11.7	12.4	13.1	13.6	
.73					3.90	13.50			284	10.7	11.75	12.75	13.5	14.1	14.25	
.69	.24	.20	.016	.016		6.31			283	9.8	12.65	14.5	15.5	16.1	16.55	
.59	.22	.06	.028	.023	2.86	18.81			1015		12.15	13.2	13.75	14.3	14.75	
.63	.58	.22	.009	.024			0.69		906		11.8	12.8	13.75	14.6	15.4	
.55	.25	.71	.036	.003			1.58		906		12.2	13.6	14.6	15.5		
.33	.13	.23	.038	.011		1.71			1416		12.4	13.3	14.1	15.0	16.0	17.2
.45	.15	.22	.022	.011		2.20			1416		12.3	13.1	14.0	15.0	16.2	17.55
.38	.13	.24	.022	.011		2.07			1416		12.35	13.1	13.8	14.75	15.7	16.85
.36	.19	.26	.023	.013		1.84			1416		12.0	12.9	13.8	14.8	16.0	

Table 31.—Fe-Cr-Si; Fe-Mn-Si; Fe-Ni-Si; Fe-Si (Steels Containing Si, and Ferro-Silicon) (2) (*v. also* Tables 36, 37)

% composition							Range, °C	$10^6\alpha_{t_1}^{t_2}$											
Fe	Cr	Mn	Ni	Si	C	P	Ind. No.	15 to 100°	100 to 200°	200 to 300°	300 to 400°	400 to 500°	500 to 600°	600 to 700°	700 to 800°	800 to 900°	900 to 1000°	15 to 900°	15 to 1000°
92.4	3.12	0.0	0.0	0.56	2.66		1235	10.23	10.89	13.57	14.65	16.02	15.99	15.37	10.10	23.25	27.24	14.53	
								* 9.52	8.78	13.67	21.03	4.57	11.83	16.38	8.42	18.92	28.97	12.61	
89.5	7.4	0.0	0.0	2.38	1.62		1235	10.94	10.49	12.07	14.55	16.02	18.18	16.26	17.92	17.00		14.90	
								* 9.41	10.29	10.68	12.56	13.24	12.63	14.90	18.64	26.53	36.53	14.40	
85†	0.0	9.33	0.0	1.91	3.63			16.00	11.89	13.57	17.64	19.60	19.66	14.96	19.49	20.25	11.73		16.53
								*12.70	14.28	15.26	18.42	20.38	17.16	15.35	18.59	16.78	15.66		16.54
11.6	0.0	68	0.0	19.6	0.65			13.05	13.48	15.27	19.13	19.79	19.56	19.82	21.56	21.91		18.27	
								‡13.29	15.58	14.96	16.43	16.10	16.77	16.94	18.69	21.33		16.75	
85†	0.0	0.0	9.9	4.27	0.58			10.82	11.98	14.36	17.73	11.93	11.92	12.99	20.61	25.61		15.41	
								§10.47	11.89	12.37	11.86	14.63	8.84	11.02	12.75	20.30		13.29	
59†	0.0	0.2	22.6	6.93	0.35	0.9		11.05	11.78	12.97	16.05	17.51	19.17	17.15	22.27	16.59		16.15	
								§11.17	12.58	14.06	15.34	14.82	14.70	13.98	16.93	20.37		14.95	
93.7†	0.0	0.2	0.0	1.65	3.04	1.3	661	8.47	9.29	10.87	12.76	12.94	14.32	13.90	16.46	19.01	14.62		13.34
								*10.00	7.39	8.58	14.16	14.54	3.68	13.02	17.47	27.65	23.03		14.02
83†				17				8.82	10.19	11.67	14.25	15.73	17.09	16.47	16.94	15.33	17.18		14.45
								*10.35	10.89	12.57	14.15	14.63	15.20	15.77	18.33	14.73	17.57		14.49
68†				32				12.11	11.18	12.87	13.45	15.02	14.70	14.48	15.06	14.24	16.00		13.97

* Values on this line for alloy: Tp 1000° Q_w 15°. † By difference. ‡ Tp 600° Q_w 15°. § Tp 900° Q_w 15°.

Table 34.—Mo (Commercially Pure) (71)

No.	Description	% composition				$10^6\alpha_{t_1}^{t_2}$ (heating)								$10^6\alpha_{t_1}^{t_2}$ (cooling)			$100\frac{\Delta l}{l}$ after test
		Fe	Si	Ca	W	25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	25 to 250°C	250 to 500°C	25 to 500°C	500 to 25°C	500 to 250°C	250 to 25°C	
1	Ingot, from fine powder............					5.4	5.1	5.2	5.6	5.7	5.3	5.5	5.4	5.6	5.8	5.3	−0.010
2	No. 1 swaged to 0.25 in. diam......	0.03	0.03		1.85	4.9	5.1	5.4	5.7	7.4	5.1	6.3	5.8	5.8	5.9	5.6	−0.001
3	No. 2 swaged to 0.175 in. diam.....	0.05	0.014	0.005	1.80	4.9	5.1	5.2	5.4	6.2	5.1	5.7	5.4	5.5	5.8	5.3	−0.007
4	No. 3 swaged to 0.1 in. diam.......					4.6	4.8	5.2	5.9	6.4	4.8	6.0	5.4	5.0	5.3	4.6	+0.022
5	Ingot, from coarse powder..........	0.04	0.003			3.7	5.5	4.8	5.8	5.8	4.6	5.7	5.2	5.4	5.7	5.1	−0.009
6	Similar ingot to No. 5..............					5.0	5.0	5.2	5.0	3.4	5.1	4.4	4.7	5.5	6.0	4.9	−0.036
7	No. 6 swaged to 0.25 in. diam......				Cu	4.8	4.8	5.2	6.4	7.0	4.9	6.4	5.7	5.5	5.7	5.3	+0.009
8	No. 7 swaged to 0.175 in. diam.....	0.11	0.003		0.014	4.5	4.6	5.1	5.1	6.5	4.7	5.6	5.2	4.8	5.5	4.1	0.017
9	No. 8 swaged to 0.1 in. diam.......	0.03	0.004		0.006	4.5	4.3	4.4	6.1	7.2	4.4	6.2	5.3	5.1	5.3	4.8	0.012
10	Ingot, from coarse powder and swaged to 0.25 in. diam	0.10	0.017	0.005		4.6	4.9	5.2	6.5	7.0	4.8	6.5	5.7	5.2	5.3	4.9	0.026
11	No. 10 swaged to 0.175 in. diam.....					4.8	5.1	5.4	5.9	6.7	5.0	6.1	5.6	5.6	6.0	5.1	0.002
12	No. 11 swaged to 0.1 in. diam......	0.11	0.007	0.010	0.005	3.7	4.7	4.9	4.9	5.8	4.5	5.2	4.9	4.0	3.8	4.2	0.043

Table 35.—Ni (Commercially Pure) (130)

% composition							Treatment	$10^6\alpha_{t_1}^{t_2}$								
Ni	Cu	Fe	Mn	C	Si	S		25 to 100°C	100 to 200°C	200 to 300°C	300 to 400°C	400 to 500°C	500 to 600°C	25 to 300°C	300 to 600°C	25 to 600°C
99.06	0.12	0.37	0.19	0.12	0.12	0.027	Hot rolled..............	13.2	14.4	15.3	16.8	15.5	16.9	14.4	16.4	15.4
							Annealed 1 hr at 870°C...	13.3	14.5	15.4	16.4	16.6	16.3	14.5	16.5	15.5
99.02	.12	.37	.22	.08	.16	.020	Hot rolled..............	12.9	14.5	15.4	16.9	16.5	16.8	14.4	16.7	15.6
							Annealed 1 hr at 900°C...	13.3	14.5	15.5	16.7	16.3	16.9	14.5	16.6	15.6
98.76	.17	.38	.18	.22	.26	.020	Hot rolled..............	13.0	14.2	15.7	15.9	15.7	14.4	14.4	15.3	14.9
							Annealed 1 hr at 900°C...	13.3	14.2	15.6	16.3	16.2	16.3	14.5	16.3	15.4
97.05	.15	.44	2.08	.09	.15	.029	Hot rolled..............	13.1	13.5	14.8	17.2	16.6	17.1	13.8	17.0	15.5
							Annealed 1 hr at 870°C...	13.5	14.3	15.8	16.0	16.6	17.3	14.6	16.6	15.7
94.21	.14	.46	4.92	.12 Co	.10	.030	Hot rolled..............	13.2	14.1	15.4	15.9	16.7	17.3	14.3	16.7	15.5
							Annealed 1 hr at 870°C...	13.3	14.1	15.4	15.9	16.6	17.6	14.3	16.7	15.6
97.0*	.3	.8	1.6	<1			α_{25}^{200}, 14; α_{200}^{400}, 16; α_{400}^{600}, 16; α_{600}^{840}, 20; α_{25}^{840}, 17†									

No marked abnormality is shown between 300 and 400°C by first 5 samples; *cf.* pure Ni in Table 1.

* Spark plug electrodes (133). † These values are for $10^6\alpha_{t_1}^{t_2}$.

TABLE 36.—NI-FE-SI; NI-SI-FE (2)

Composition and treatment	No. / Range, °C	$10^6\alpha_{t_1}^{t_2}$ 1	1a	2	2a	3	3a
1. Ni, 80.6; Si, 16.2; Fe, 2.5 1a. Same, Tp 1000° Q_W 15° 2. Ni, 75; Si, 17.01; Fe, 7.6 2a. Same, Tp 1000° Q_W 15° 3. Ni, 39; Fe, 28.3; Si, 17.86; Mn, 13.1; C, 0.3 3a. Same, Tp 600° Q_W 15°	15 to 100	8.58	8.82	8.58	8.82	11.29	9.17
	100 to 200	9.09	11.19	9.19	10.29	12.18	9.08
	200 to 300	9.58	9.88	9.98	11.37	15.46	8.18
	300 to 400	11.37	11.77	11.56	12.36	17.03	9.77
	400 to 500	13.25	13.95	12.76	13.74	17.70	12.95
	500 to 600	14.22	15.12	15.12	14.22	19.16	13.23
	600 to 700	14.10	16.09	14.6	14.00	20.71	16.40
	700 to 800	13.49	16.66	14.68	14.08	21.75	16.86
	800 to 900	12.48	15.34	13.47	14.06	17.66	15.05
	900 to 1000	15.33	14.93	13.05	18.39	14.87	12.66
	15 to 1000	12.20	13.37	12.35	13.20	16.88	12.39

TABLE 37.—SI-FE-C (2)

Composition and treatment	No. / Range, °C	$10^6\alpha_{t_1}^{t_2}$ 1	2	3	4
1. Cast Si with *ca.* 2% of	15 to 100	6.00	6.58	6.94	9.17
SiC + Tr. Fe-Si. Sud-	100 to 200	5.18	5.39	4.79	8.78
den increase in α between	200 to 300	4.69	4.59	4.99	9.18
700 and 805°; anomaly	300 to 400	4.29	4.19	4.89	10.07
between 700 and 1000°	400 to 500	3.89	4.39	4.99	10.46
2. Industrial SiC (crystal-	500 to 600	3.99	4.28	4.98	11.84
lized)	600 to 700	4.88	4.18	5.68	13.52
3. Industrial Fe-Si with	700 to 800	10.46	4.38	6.67	47.36
75% Si	800 to 900	3.28	2.98	5.27	24.90
4. Industrial Fe-Si with	900 to 1000	0.19	2.68	4.27	15.96
50% Si	15 to 1000	4.68	4.35	5.45	16.23

TABLE 38.—COEFFICIENT OF CUBICAL EXPANSION OF ALLOYS IN THE RANGE 0 TO 100°C $V_t = V_0[1 + At + Bt^2]$ (95)

Composition	10^6A	10^9B	Composition	10^6A	10^9B
Ag, 4; Au	51.66		Bi, 44; Sn	37.93	27.1
Ag, 71.6; Au, 28.4	44.13	13.0	Sn, 2; Bi	49.97	10.1
Ag; Au	49.16		Cd; Pb	90.05	13.3
Ag, 36.1; Au, 63.9	48.84	55.2	Cu, 71; Zn, 29	51.61	55.8
Ag; Au, 4	31.15	118.5	Pb, 4; Sn	80.87	33.2
Ag, 2; Pt	42.46	32.2	Sn, 4; Pb	62.0	98.8
Au, 2; Cu	40.15	64.2	Sn, 7; Au, 2	41.65	26.3
Bi, 24; Pb	38.68	21.8	Sn, 2; Au	39.44	28.9
Pb, 2; Bi	84.62	15.9	Sn, 6; Zn	62.36	82.2
			Sn, 4; Zn	63.77	80.7

COEFFICIENTS OF EXPANSION OF LIQUID ALLOYS AND AMALGAMS

See also Tables 41–45; for definitions, *v.* p. 459.

TABLE 39.—CUBICAL EXPANSION OF LIQUID ALLOYS AND AMALGAMS

% composition	Approx. M. P., °C	10^6A*	Range, °C	Lit.
Bi, 50; Hg, 50	162.7	134	163 to 280	(19.1)
Bi, 67; Pb, 33		138	130	(138)
Bi, 57; Sn, 43		122	140	(138)
Bi, 70; Tl, 30		131	212–325	(102)
Cd, 90; Zn, 10		153	265	(138)
Hg, 80; Pb, 20	102	161	250 to 300	(19.1)
Hg, 66; Pb, 34	125	143	250 to 300	(19.1)
Hg, 40; Pb, 60	193	139	250 to 300	(19.1)
Hg, 25; Pb, 75	236	135	250 to 300	(19.1)

TABLE 39.—CUBICAL EXPANSION OF LIQUID ALLOYS AND AMALGAMS (*Continued*)

% composition	Approx. M. P., °C	10^6A*	Range, °C	Lit.
Hg, 77.3; Sn, 22.7	103.5	125	200 to 300	(19.1)
Hg, 63; Sn, 37	131	121	200 to 300	(19.1)
Hg, 46; Sn, 54	166	117	200 to 300	(19.1)
Hg, 29.8; Sn, 70.2	193	113	200 to 300	(19.1)
Hg; Sn (d_4^t; $t°$)				
13.3835; 14.6		174.5	18 to 101	(91)
13.1807; 20.2		161.9	20 to 98	(91)
Hg, 95.1; Tl, 4.9		179	20 to 30	(115)
Hg, 83.0; Tl, 17.0		175	20 to 30	(115)
Hg, 79.0; Tl, 21.0		161	20 to 30	(115)
Hg, 66.0; Tl, 34.0		140	20 to 30	(115)
Hg, 58.1; Tl, 42.9		157	20 to 30	(115)
Hg, 86; Zn, 14	152	184	300 to 350	(19.1)
Hg, 80; Zn, 20	200	181	300 to 350	(19.1)
Hg, 77; Zn, 23	217	153	300 to 350	(19.1)
Hg, 60.6; Zn, 39.4	288	146	300 to 350	(19.1)
Hg, 50.7; Zn, 49.3	316.5	*ca.* 200	330 to 360	(19.1)
K, 39; Na, 23†	4.5	286	10 to 100	(65)
Pb, 90; Sb, 10		123	250	(138)
Pb, 64; Sn, 36		127	262 to 356	(138)
Pb, 13; Sn, 87		112	249 to 355	(138)
Sn, 68; Cd, 32		123	175	(138)
Sn, 70; Tl, 30		118	200 to 300	(102)
Tl, 80; Sb, 20		227	200 to 225	(102)

* If only one temperature is given, $A = A_t$; if a temperature range, $A = A_{t_1}^{t_2}$.
† Equal atomic weights of each.

VOLUME CHANGE ON FUSION AND SOLIDIFICATION, "MOLD SHRINKAGE"

Arrangement.—No definite arrangement is strictly followed in this section. Its scope and content will be seen by inspection.

TABLE 40.—FUSION OF PURE METALS (V_S = VOLUME OF SOLID AT M. P.)

Metal	Approx. M. P., °C	$100\frac{\Delta V}{V_S}$	*P. E.*	Lit.
Ag	960	4.5	±0.5	(45, 118)
Al, 99	658	6.7		(9, 43)
Al, 99.65		6.3		(45)
Au	1063	5.2		(45)
Bi	270	−3.3	±0.1	(11, 45, 135, 138)
Cd	321	4.7	±0.1	(45, 138)
Cs	26	2.5	±0.2	(42, 64)
Cu	1083	4.1	±0.1	(9, 10, 45)
K	62.5	2.5	±0.3	(13, 45, 64, 65)
Li	185	1.5		(138)
Mg	650	4.2		(44)
Na	98	2.5	±0.1	(6, 13, 14, 45, 65, 135)
Pb	325	3.4	±0.1	(46)
Rb	38	2.5	±0.2	(45, 64)
Sb	630	1.4		(135)
Sn	232	2.7	±0.1	(11, 45, 135, 138)
Tl	300	3.1		(135)
		3.2		(45)
		4.3		(102)
Zn	420	6.5	±0.5	(135)

TABLE 41.—SOLIDIFICATION OF PURE METALS (143)

% metal	Casting temp., °C	F. P., °C	$-100\frac{\Delta l}{l}$		
			At F. P.	In solid state*	Total
Al, 99.2......	800 to 850	683			1.78
Bi, 99.8......	500	261		0.29	
Cu, 99.16....	1250	1060		1.40	1.42
Pb, 98.2......	500 to 600	326	0.075	0.75	0.825
Sn, 99.8 to 100	500 to 550	225	0.01 to 0.15		0.44 to 0.55
Zn, 97.3......	650 to 750	416	0.08	1.32	1.40

* Final temperature is 15 to 20°C.

TABLE 42.—SOLIDIFICATION OF BI-SN (9, 10)

% Bi	A_t for liquid	Range, °C	$-100\frac{\Delta V}{V_{800°}}$			
			800°C to F. P.	At F. P.	F. P. to 20°	800 to to 20°C
100	0.00012	267.5 to 800	6.2	−3.01	1.32	4.51
90	0.00014	233 to 800	7.1			4.10
75	0.00014	185 to 800	7.6			7.17
58	0.00012	136.5 to 800	7.35	−1.12	1.36	7.58
40	0.00011	173 to 800	6.5			8.12
25	0.00011	199 to 800	5.95			8.32
15	0.00014	215 to 800	7.5			10.85
10	0.00013_5	220 to 800	7.4			13.4
0	0.00010_4	360 to 630	5.6	+2.7	1.64	9.99

TABLE 43.—SOLIDIFICATION OF CU-AL (9, 10)

% Cu	A_t for liquid	Range, °C	$-100\frac{\Delta V}{V_{1200°}}$			
			1200°C to F. P.	At F. P.	F. P. to 20°C	Total
93	0.00014	1070 to 1200	1.73	4.25	5.08	11.06
85	0.00012	1035 to 1200	2.04	3.85	5.80	11.7
77.5	0.00013	950 to 1200	3.24	4.06	4.51	11.8
65	0.00012	725 to 1200	5.43			9.63
54	0.00013	585 to 1200	7.6			11.3
18	0.00013	543 to 1200	6.7			16.1
0	0.00012_5	657 to 1200	6.5	(5.8)	(4.3)	16.5

TABLE 44.—SOLIDIFICATION OF CU-SN (9, 10)

% Cu	A_t for liquid	Range, °C	$-100\frac{\Delta V}{V_{1200°}}$			
			1200°C to F. P.	At F. P.	F. P. to 20°C	Total
100	0.00020	1084 to 1200	2.19	3.91	6.4	12.5
92	0.00015	1018 to 1200	2.57	5.06	5.52	12.85
82	0.00016	920 to 1200	4.25	4.25	4.79	13.28
71	0.00014	780 to 1200	5.53	3.61	4.68	13.83
62	0.00011	724 to 1200	5.58	3.28	5.88	14.76
35	0.00011	600 to 1200	6.18			13.35

TABLE 45.—SOLIDIFICATION OF CU-SB (9, 10)

% Cu	A_t for liquid	Range, °C	$-100\frac{\Delta V}{V_{1100°}}$	
			1100°C to F. P.	1100 to 17°C
85	0.00016	940 to 1100	2.67	10.4
72	0.00012	646 to 1100	5.26	11.8
61	0.00011	670 to 1100	4.45	12.6
51.5	0.00011_5	665 to 1100	4.75	13.8
30	0.00012	550 to 1100	4.85	10.1
10	0.00011_5	580 to 1100	4.55	7.9
0	0.00010_4	630 to 1100	4.45	7.32

TABLE 46.—SPECIFIC VOLUME OF SB, 81.6; AL, 18.4 (118)

Temp., °C	$\frac{1}{d_4^t}$
700	0.240
800	0.241
900	0.241
1000	0.230
1025	0.221
1100	0.213
1135	0.211
1200	0.215

TABLE 47.—SOLIDIFICATION OF MISCELLANEOUS ALLOYS (143)

% composition	Casting temp., °C	Arrest temp., °C	$-100\frac{\Delta l}{l}$*
Pb, 80.82; Sn, 18.27............	650	251	0.56
Pb, 29.1; Sn, 70.01............	550	174	0.44
Pb, 18.39; Sn, 80.99............	550	180	0.50
Pb, 80.61; Sb, 19.2............	560 to 750	239	0.54
Pb, 85.2; Sb, 14.68............	450 to 500	232	0.56
Sn, 50.83; Zn, 49.04............	550	200	0.50
Sn, 85.4; Zn, 14.52............	500	195	0.46
Sn, 95.15; Zn, 4.81............	500	190	0.49

% composition	Casting temp., °C	T_1 °C† commencement of solidification		T_E °C‡	$100\frac{\Delta l}{l}$	T_S, °C§	$-100\frac{\Delta l}{l}$*
Cu, 83.45; Zn, 16.24........	1000 to 1050	993		1000	0.3	973	2.17
Cu, 66.6; Zn, 32.9........	950	902		904	0.03	870	1.98
Cu, 63.1; Zn, 36.24........	870 to 950	874		928	0.03	877	1.97
Cu, 63.93; Zn, 35.25........	900 to 1000	881		990	0.033	879	1.9
		T_1°C †	T_2°C †				
Cu, 94.7; Sn 5.08...........	1050	1035		1032	0.085	786	1.66
Cu, 89.65; Sn, 10.23........	995 to 1150	996		980	0.122	706	1.44
Cu, 80.66; Sn, 19.08........	900		760	835	0.01	752	1.52
Cu, 61.57; Ni, 16.1; Zn, 22.16	1100	1020	955	1068	0.045	917	2.025
Cu, 56.2; Ni, 20.4; Zn, 23.36	1065 to 1090	1060	1025	1049	0.039	924	2.05
Cu, 51.4; Ni, 26.22; Zn, 22.3	1150	1087	890	1080	0.027	949	2.03
Cu, 46.1; Ni, 35.8; Zn, 18.0.	1170 to 1200	1085		1090	0.032	1010	1.935

% composition	Casting temp.	Arrest points, t°C	T_E, °C‡	$100\frac{\Delta l}{l}$	T_S, °C§	$-100\frac{\Delta l}{l}$*
Cu, 87.1; Sn, 2.68; Zn, 8.05; Pb, 2.28	1000°C	992, 895, 825, 685	973	0.025	840	1.76
Cu, 81.06; Sn, 17.5; Zn, 1.53..	950 to 1000°C	873, 775, 737, 603	854	.024	756	1.50
Cu, 88.75; Sn, 9.65; Zn, 1.6...	950 to 1020°C	977, 890, 824, 745	955	.058	726	1.47
Cu, 86.65; Sn, 9.84; Zn, 2.0; Pb, 1.44	1000°C	965, 840, 778, (848)	944	.075	750	1.47
Zn, 79.44; Sn, 14.48; Cu, 4.35; Pb, 1.66................	500 to 500°C	379			374	1.02

TABLE 47.—SOLIDIFICATION OF MISCELLANEOUS ALLOYS (143).—(*Continued*)

% composition	Casting temp.	Arrest points, t°C	T_E, °C‡	$100\frac{\Delta l}{l}$	T_S, °C§	$-100\frac{\Delta l}{l}$*
Zn, 51.22; Sn, 45.84; Cu, 1.9; Pb, 0.94	550 to 560°C	340			334	0.73
Pb, 78.89; Sb, 12.5; Cu, 8.45	600 to 650°C	250, 230			266	0.55
Sn, 19.8; Pb, 58.84; Sb, 21.4	600°C	263, 238			247	0.49
Sn, 85.42; Sb, 9.45; Cu, 5.1	500 to 550°C	225			225	0.51
Sn, 90.2; Sb, 8.0; Cu, 1.85	600 to 700°C	228			226	0.555
Sn, 70.83; Pb, 9.21; Sb, 15.1; Cu, 4.94	550 to 600°C	259, 187			228	0.425

* The total linear shrinkages given above take place during cooling from the temperatures indicated in the table to atmospheric temperature (15 to 20°C).

† T_1, T_2, arrest points. ‡ T_E, expansion begins. § T_S, shrinkage begins.

TABLE 48.—SOLIDIFICATION OF CU-SN-X (BRONZES) (97)

% composition	Casting temp., °C	F. P., °C	Final temp., °C	Mold temp., °C	Expansion $100\frac{\Delta l}{l}$*	Shrinkage $-100\frac{\Delta l}{l}$
Cu, 92; Sn, 8	990	960	300	250	0.04	1.54
	970	960	500	200	.06	1.56
	980	960	500	200	.05	1.51
Cu, 92; Sn, 4; Al, 4	1170	1010	500	200	.05	1.88
	1080	1010	500	200	.04	1.86
Cu, 92; Sn, 7; Bi, 1	990	980	500	200	.065	1.41
	1030	980	500	250	.05	1.46
Cu, 92; Sn, 8; Bi, 0.5	1020	980	500	150	.05	1.47
	1000	980	500	200	.06	1.42
Cu, 90; Sn, 8; Co, 2	1000	970	400	250	.05	1.63
Cu, 90; Sn, 6; Co, 4	1080		400	300	.05	1.58
Cu, 90; Sn, 4; Co, 6	1040		400	300	.03	1.70
Cu, 90; Sn, 2; Co, 8	1030		300	150	.05	1.69
Cu, 90; Co, 10	1080		350	300	.05	
Cu, 92; Sn, 7; Fe, 1	990	990	500	250	.03	1.67
	1030	1010	500	250	.035	1.72
Cu, 92; Sn, 6; Fe, 2	1050	1010	500	200	.04	1.60
	1050	1010	500	250	.04	1.63
Cu, 92; Sn, 5; Mn, 3	1130	990	600	250	.03	1.54
	1100	990	550	200	.035	1.54
Cu, 92; Sn, 3; Mn, 5	1160	1010	600	200	.02	1.50
	1140	1000	500	250	.025	1.53
Cu, 92; Sn, 5; Ni, 3	1070	1040	480	250	.03	1.71
	1050	1040	500	200	.04	1.71
Cu, 90; Sn, 5; Ni, 5				250	.035	1.70
	1070	1040	550	200	.04	1.76
Cu, 92; Sn, 8; P, 2	1160	970	500	200	.015	1.43
	1080	960	500	200	.01	1.45
Cu, 92; Sn, 7; Pb, 1	1010	970	500	250	.06	1.58
	990	970	500	200	.05	1.50
Cu, 92; Sn, 6; Pb, 2	970	965	500	100	.05	1.48
	1050	980	500	250	.055	1.54
Cu, 92; Sn, 5; Pb, 3	985	980	500	300	.035	1.685
	990	980	500	200	.04	1.69
Cu, 92; Sn, 7; Sb, 1	1020	990	500	200	.04	1.58
	1000	985	500	150	.05	1.54
Cu, 92; Sn, 6; Sb, 2	1020	980	550	250	.05	1.53
	980	970	500	250	.035	1.47
Cu, 92; Sn, 5; Sb, 3	1010	970	530	200	.025	1.45
	995	970	500	100	.02	1.43
Cu, 92; Sn, 5; Si, 3	1020	970	500	250	.02	1.71
	1010	960	500	200	.01	1.75
Cu, 92; Sn, 8; W, 0.12	1140	1080	600	200	.025	1.52
	1150	1080	500	100	.04	1.49
Cu, 92; Sn, 8; W, 0.15	1160	1010	600	200	.035	1.52
	1090	1020	500	200	.02	1.50
Cu, 90; Sn, 8; Zn, 2	1080	970	500	200	.07	1.56
	990	960	500	300	.048	1.51
Cu, 90; Sn, 6; Zn, 4	1000	970	500	200	.04	1.57
	980	970	550	150	.05	1.64
Cu, 90; Sn, 4; Zn, 6	1080	1000	500	200	.05	1.59
	1010	995	500	350	.035	1.66

TABLE 48.—SOLIDIFICATION OF CU-SN-X (BRONZES) (97).—(*Continued*)

% composition	Casting temp., °C	F. P., °C	Final temp., °C	Mold temp., °C	Expansion $100\frac{\Delta l}{l}$*	Shrinkage $-100\frac{\Delta l}{l}$
Cu, 80; Sn, 10; Zn, 10	1060	975	500	200	0.03	1.34
	1080	975	500	350	.025	1.33
Cu, 82; Sn, 10; Zn, 8	1020	920	500	200	.025	1.35
	1040	910	500	400	.04	1.39
Cu, 84; Sn, 10; Zn, 6	1060	930	500	200	.03	1.38
	1090	940	500	300	.03	1.43
Cu, 86; Sn, 10; Zn, 4	1030	950	500	250	.03	1.47
	1020	940	500	250	.03	1.45
Cu, 88; Sn, 10; Zn, 2	1020	960	500	300	.03	1.49
	990	960	500	250	.052	1.51
Cu, 80; Sn, 8; Zn, 12	1040	940	500	250	.03	1.43
	1000	930	500	150	.04	1.46
Cu, 80; Sn, 6; Zn, 14	1000	870	500	250	.04	1.47
	1040	890	500	250	.025	1.54

* In all the above alloys a slight increase in length always occurred before the commencement of the shrinkage.

TABLE 49.—EFFECT OF MN CONTENT ON SHRINKAGE OF GRAY CAST IRON (28)

% Mn	$-100\frac{\Delta l}{l}$*	% Mn	$-100\frac{\Delta l}{l}$*
1.00	0.90	6.62	1.42
1.61	1.02	9.89	1.52
2.65	1.07	11.15	1.74
3.45	1.01	17.51	1.74
4.19	1.26	30.30	1.96
5.15	1.31		

* Total shrinkage from F. P. to 20°C.

TABLE 50.—EFFECT OF MN CONTENT ON EXPANSION DURING SOLIDIFICATION OF GRAY CAST IRON (28)

% composition				$100\frac{\Delta l}{l}$
C		Mn	Si	
Total	Graphite			
3.56	2.87	0.55	2.45	0.161
3.70	3.39	1.00	2.46	.219
3.63	3.16	1.61	2.35	.116
3.60	3.25	2.23	2.35	.152
3.60	3.33	2.65	2.39	.159
3.70	3.12	3.45	2.48	.162
3.80	2.94	4.19	2.44	.178
3.12	2.69	5.15	2.40	.155
3.40	2.65	5.83	2.34	.161
3.24	2.60	6.62	2.40	.190
3.85	2.15	8.35	2.38	.165
3.85	2.10	9.89	2.45	.257
3.95	1.98	10.30	2.41	.241
4.00	1.85	11.15	2.48	.188
4.25	1.14	17.57	2.54	.281
3.89		30.30	2.96	.097

TABLE 51.—EFFECT OF MN CONTENT ON EXPANSION DURING SOLIDIFICATION OF WHITE CAST IRON (28)

% composition			$100\frac{\Delta l}{l}$
C	Mn	Si	
3.19	0.43	0.053	0.022
3.24	0.82		.032
3.28	1.48		.058
3.05	1.67	0.055	.068
3.09	2.37		.066
3.19	2.82		.049
3.12	3.50	0.050	.034

TABLE 51.—EFFECT OF MN CONTENT ON EXPANSION DURING SOLIDIFICATION OF WHITE CAST IRON (28).—(*Continued*)

% composition			$100\frac{\Delta l}{l}$
C	Mn	Si	
3.14	4.42		0.019
3.19	5.25	0.061	.015
3.45	5.40	0.083	.039
3.43	6.30		.058
3.39	7.20	0.081	.082
3.36	9.00	0.068	.058
3.45	9.12		.068
3.50	10.40		.058
3.46	10.67	0.072	.078
3.50	12.35		.087
3.49	13.50		.068
3.65	13.70	0.085	.053
3.41	14.84		.024
3.80	16.00		.068
3.45	16.20	0.100	.058
3.76	17.05		.339
3.91	18.65		.008
3.81	19.65		.029
3.85	23.30	0.120	.097
3.95	30.50	0.173	.097
3.85	34.10	0.156	.097
3.93	38.55	0.155	.102

CHANGES IN VOLUME DUE TO TEMPERING

TABLE 52.—CHANGES IN VOLUME OF ALLOYS DUE TO TEMPERING (101)

% composition	Heated to °C	Tempered at °C	$100\frac{\Delta V}{V}$
Cu, 90.5; Al, 9.5	1000	400	−0.03
	1000	900	−0.08
	1000	1000	−0.16
Cu, 86.5; Al, 13.5	1000	650	−0.55
	1000	900	−0.42
	1000	1000	−0.58
Cu, 83.4; Al, 16.6	1000	400	−0.06
	1000	650	−0.15
	1000	1000	−0.15
Cu, 74.1; Al, 25.9	700	700	0.08
Cu, 74.9; Sn, 25.1	700	700	−0.10
Cu, 72.7; Sn, 28.1	700	700	−0.30
Cu, 71.9; Sn, 28.1	700	700	−0.22
	700	600	−0.27
Fe with 0.58 C	1000	700	0.46
	1000	750	0.46
	1000	800	0.47
	1000	900	0.47
	1000	1000	0.46
Fe with 0.70 C	1000	700	0.67
	1000	750	0.73
	1000	800	0.75
	1000	900	0.82
	1000	1000	0.85
Fe with 0.83 C	1000	650	0.17
	1000	700	0.23
	1000	750	0.96
	1000	800	0.99
	1000	900	1.10
	1000	1000	1.13

TABLE 52.—CHANGES IN VOLUME OF ALLOYS DUE TO TEMPERING (101).—(*Continued*)

% composition	Heated to °C	Tempered at °C	$100\frac{\Delta V}{V}$
Zn, 80.3; Cu, 19.7	600	600	−0.08
Zn, 75.5; Cu, 24.5	600	600	−0.32
Zn, 74.5; Cu, 25.5	600	600	−0.40
Zn, 57.8; Cu, 42.2	800	750	0.24
Same (reheated)	800	750	0.40
Zn, 47.4; Cu, 52.6	800	750	0.16

See also Table 12, p. 516.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Ayres, *2*, **20**: 38; 05. (2) Baraduc-Muller, *74*, **7**: 657; 10. (3) Bein, *88*, **14**: 1097; 12. (4) Benedicks, *34*, **179**: 389; 24. (5) Benoît, *238*, **6**; 1888. (6) Bernini and Cantoni, *59*, **8**: 241; 14. (7) Bernini and Cantoni, *72*, **47**: 630; 14. (8) Borelius and Johansson, *8*, **75**: 23; 24. (9) Bornemann and Sauerwald, *95*, **14**: 145; 22.

(10) Bornemann and Sauerwald, *95*, **14**: 254; 22. (11) Bornemann and Siebe, *95*, **14**: 329; 22. (12) Braesco, *34*, **170**: 103; 20. (13) Bridgman, *2*, **3**: 153; 14. (14) Bridgman, *2*, **6**: 1; 15. (15) Bridgman, *65*, **56**: 61; 20. (16) Bridgman, *197*, **10**: 411; 24. (17) Brislee, *135*, **105**: 3; 12. (18) Burgess, Crowe, Rawdon, and Waltenberg, *32*, No. **38**; 14. (19) Cattaneo, *22*, **7 I**: 88; 91. (19.1) Cattaneo, *23*, **25**: 492; 89.

(20) Charpy and Grenet, *34*, **134**: 540; 02. (21) Charpy and Grenet, *34*, **136**: 92; 03. (22) Chevenard, *34*, **159**: 53; 14. (23) Chevenard, *34*, **164**: 916; 17. (24) Chevenard, *34*, **174**: 109; 22. (25) Chevenard, *34*, **180**: 1927; 25. (26) Chevenard, *74*, **11**: 841; 14. (27) Chevenard, *74*, **14**: 610; 17. (28) Coe, *115*, **90**: 581; 10. (29) Cohen and Olie, *7*, **71**: 385; 10.

(30) Colby, *2*, **30**: 506; 10. (31) Day and Sosman, *12*, **29**: 93; 10. (32) Day and Sosman, *45*, **4**: 490; 12. *128*, **2**: 284; 12. (33) Day, Sosman and Hostetter, *12*, **37**: 1; 14. (34) Deuss, *242*, **56**: 15; 11. (35) Dewar, *5*, **70**: 237; 02. (36) Disch, *96*, **5**: 173; 21. (37) Dittenberger, *98*, **46**: 1532; 02. (38) Dodge, *2*, **11**: 311; 18. (39) Dorsey, *2*, **25**: 88; 07.

(40) Dorsey, *2*, **27**: 1; 08. (41) Driesen, *139*, **11**: 129; 14. (42) Eckhardt and Graefe, *93*, **23**: 378; 00. (43) Edwards and Moorman, *33*, **24**: 61; 21. (44) Edwards and Taylor, *80*, **69**: 1070; 23. (45) Endo, *47*, **30**: 121; 23. (46) Endo, *159*, **13**: 219; 24. (47) Fizeau, *34*, **62**: 1101; 66. (48) Fizeau, *34*, **64**: 314; 67. (49) Fizeau, *34*, **66**: 1072; 68.

(50) Fizeau, *34*, **68**: 1125; 69. (51) Fontana, *22*, **3**: 129; 94. (52) Forsythe, Nela Park Laboratory, Cleveland, Ohio, *O*. (53) Goucher, *3*, **48**: 229; 24. (54) Gray, *80*, **64**: 488; 21. (55) Griffiths and Griffiths, *67*, **27**: 477; 15. (56) Grüneisen, *8*, **33**: 33, 65; 10. (57) Grüneisen and Goens, *63*, **24**: 506; 23. (58) Guillaume, *La Convention du Metre*. Paris, Gauthier, 1902. (59) Guillaume, *Les Applications des Aciers au Nickel*. Paris, Gauthier, 1904.

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(70) Hidnert, *31*, No. **497**; 25. (71) Hidnert and Gero, *31*, No. **488**; 24. (71.1) Hidnert and Sweeney, U. S. Bur. Standards, *O*. (71.2) Hidnert and Sweeney, *31*, No. **515**; 25. (72) Hodgman, *2*, **15**: 218; 20. (73) Hogness, *1*, **43**: 1621; 21. (74) Holborn and Day, *8*, **4**: 104; 01. (75) Holborn and Grüneisen, *8*, **6**: 136; 01. (76) Holborn and Valentiner, *8*, **22**: 1; 07. (77) Honda, *159*, **6**: 203; 17. (78) Honda, *159*, **7**: 59; 18. (79) Honda and Matsushita, *159*, **8**: 89; 19.

(80) Jaeger and Scheel, *101*, **40**: 150; 19. (81) Johansson, *8*, **76**: 445; 25. (82) Kaye, *5*, **85**: 430; 11. (83) Kikuta, *74E*, **19**: 579; 22. (84) Le Chatelier, *34*, **108**: 1096; 89. (85) Le Chatelier, *34*, **128**: 1444; 99. (86) Le Chatelier, *34*, **129**: 331; 99. (87) Leman, Blaschke and Werner, *243*, **32**: 155; 12. (88) Lindemann, *63*, **12**: 1197; 11. (89) Lüdeking, *8*, **34**: 21; 88.

(90) Lussana, *59*, **2**: 233; 95. (91) Lussana, *59*, **19**: 182; 10. (92) Mathews, *80*, **67**: 133; 22. (93) Matsushita, *159*, **8**: 79; 19. (94) Matsushita, *159*, **9**: 143; 20. (95) Matthiessen, *5*, **15**: 220; 66. (96) Merica and Schad, *31A*, **14**: 571; 19. (97) Miller, *192*, **9**: 63; 12. (98) Müller, *63*, **17**: 29; 16. (99) Muraoka, *8*, **13**: 307; 81.

(100) Murray, *47*, **2**: 101; 09. (101) Oknoff, *74E*, **14**: 85; 17. (102) Omodei, *427*, **16**: 67; 92. (103) Onnes and Clay, *168*, No. **95b**; 06. *64V*, **1906**: 159. (104) Onnes and Clay, *168*, Supp. No. **17**: 07. *64V*, **1907**; 243. (105) Pascal and Jouniaux, *34*, **158**: 414; 14. (106) Petruschevskii and Alexiev, *427*, **6**: 145; 82. (107) Playfair and Joule, *4*, **3**: 57; 46. (108) Quadrio-Curzio, *Bull. Acad. Gioenia, Catania*, **49**: 16; 97. (109) Quincke, *8*, **135**: 621; 68.

(110) Ramsay, *25*, **13**: 2145; 80. (111) Ramsay, *427*, **5**: 163; 81. (112) Randall, *2*, **20**: 85; 05. (113) Rauramo and Saarialho, *60*, **54A**: No. 24; 12. (114) Richards and Boyer, *1*, **43**: 274; 21. (115) Richards and Daniels, *1*, **41**: 1732; 19. (116) Roberts, *5*, **106**: 385; 24. (117) Roberts and Wrightson, *3*, **11**: 295; 81. *58*, **24**: 470; 81. (118) Sauerwald, *95*, **14**: 457; 22. (119) Sauerwald, Allendorf and Landschütz, *93*, **135**: 327; 24.
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MECHANICAL PROPERTIES OF IRON, Fe-Co, Fe-Ti, AND TITANIUM AND URANIUM STEELS

D. HANSON

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Properties of Electrolytic Iron

% composition	Treatment	*E*	*BHN*	10 × *UTS*	10 × *YP*	10× *PL*	10 × El_a	*RA*	Lit.
C, 0.029; Si, 0.004; S, 0.048; P, 0.0037; Mn, 0.0				800	780		30		(1)
	Dp			440	364		188		
	A 600°			372	312		280		
	A 800°			299	178		427		
	A 950°			296	187		373		
C, 0.031; Mn, 0.02; (Si, S, P), Tr.; Cu, 0.0	A 1000°		77	295	143	43			(5)
			77	295	137	68			(5)
O, 0.08; P, 0.007*	N_a†	21 000	66	239	131	39	500	80	(8)
		20 700	69	255	146	68	70	10	(8)
O, 0.23; P, 0.007*	N_v†	20 700		295	109	58	20	4	(8)

* Other elements absent or trace.
† Previous treatment: Ml_v R_h 80 % N.

Young's Modulus (Tension) of Fe-Co (4)

% Co	*E*/10	% Co	*E*/10	% composition of components of alloy	Fe	Co
0	2129	40	2109	C	0.09	0.24
5	2101	70	1873	Si	.11	0.14
10	2071	80	1737	Mn	.31	Ni, 1.1
15	2132	90	1973	P	.03	Fe, 1.4
20	2161	100	2079	S	.026	
30	2175			Cu	.288	

Hardness of Fe-Ti (6)

% Ti	*BHN**	% Ti	*BHN**
0.00	96	11.73	327
0.75	144	14.51	350
3.33	214	15.56	360
4.50	242	19.42	405
7.30	312	19.90	472
8.92	373	21.50	484

* Ball diam. = 5 mm; 500 kg applied ½ min.

Titanium and Uranium Steels

Fe-Cr-U-C, Cr-U Steel (7)

Cr	U	C	Mn	Si	Treatment	*UTS*	*YP*	El_a	*RA*
Composition, hundredths %									
78	17	36	53	25	835° Q_o 300°/30 C_a	170	143.4	9.0	37.2
81	31	30	57	57	850° Q_w 250°/2 h C_a	142.5	98.5	8.0	36.6
					875° Q_w 250°/2 h C_a	157.5	107	10.5	42.2
					875° Q_w 350°/2 h C_a	130.6	113.5	14	57.6
					900° Q_w 250°/2 h C_a	150.5	111.8	11	45.2

Fe-Ni-Cr-U-C, Ni-Cr-U Steel (7)

% composition	Treatment	*UTS*	*YP*	El_a	*RA*
Fe; Ni, 1.63; Cr, 0.61; U, 0.20; C, 0.36; Mn, 0.78; Si, 0.47	825° Q_o 200°/2 h C_a	175	150	11	38.2
	850° Q_o 200°/2 h C_a	175	140	13	47.2
	770° 200°/2 h C_a	150	117.3	13	50.6
	775° Q_w 350°/2 h C_a	134	106.3	13	60.2

Fe-Ni-U-C, Ni-U Steel (7)

Ni	U	C	Mn	Si	Treatment	*UTS*	*YP*	El_a	*RA*
Composition, hundredths %									
307	26	83	74	58	775° Q_o 300°/2 h C_a	172	148	2.5	4.7
313	36	25	46	20	775° Q_w 250°/2 h C_a	134	121	11.5	43.4
315	22	43	54	60	790° Q_o 250°/2 h C_a	191	158	12	43.3
					775° Q_o 250°/2 h C_a	191	162	13	44.8
					775° Q_o 250°/2 h C_a	186	148	12	47
315	40	57	62	58	790° Q_o 250°/2 h C_a	209	183	8.5	32.6
322	32	30	48	64	780° Q_o 250°/2 h C_a	183	159	9.5	34.1
					780° Q_o 250°/2 h C_a	181	161	9.0	34.1
367	36	45	72	68	775° Q_o 250°/2 h C_a	197	187	8.5	32.5
					775° Q_o 250°/2 h C_a	206	170	9.0	31.1
					800° Q_o 250°/2 h C_a	209	175	9.0	30.8

Fe-Ti-C, Ti Steels (3)

Class	Ti	C	Mn	P	S	Si	Trt	*BHN*	*UTS*	*YP*	*El*	*RA*
	Composition, thousandths %											
Low carbon Ti steel	415	122	180	18	15	47	F	99	40.7	33.9	20	68
							Q_w*	114	51.0	47.2	10	59
	879	106	140	20	15	163	F	105	45.2	37.6	19	68
							Q_w*	153	58.0	51.2	7.5	64
	1398	137	170	20	7	105	F	101	48.2	36.1	19	62
							Q_w*	126	61.3	52.1	8	58
	2570	135	310	10	17	140	F	90	45.2	34.6	17.5	68
							Q_w*	143	66.2	45.2	9.5	52
	325	760	230	15	15	292	F	207	94.1	54.9	7.5	19
							Q_w*	455				
High carbon Ti steel	640	695	240	25	24	256	F	207	94.1	52.6	9	28
							Q_w*	412				
	720	624	230	21	11	350	F	212	87.7	53.3	10	37
							Q_w*	387				
	2575	611	270	15	25	411	F	212	90.4	58.8	10.5	35
							Q_w*	340	120.3	78.5	2	4
	4630	635	315	13	18	346	F	212	89.8	57.8	9.5	34
							Q_w*	366				
	8710	650	450	16	11	163	F	248	117.5	62.5	8.5	30
							Q_w*	477	132.5	80.3	0.0	0

* Quenched from 850°C in cold water.

Fe-U-C, U Steel(7*)

U	C	Mn	Si	V	Treatment	*UTS*	*YP*	El_a	*RA*
28	25	80	39	Tr.	850° Q_w 300°/2 h C_a	130.4	114	13.5	54.4
45	28	66	47	0	850° Q_w 300°/2 h C_a	120	90.2	11	53
					850° Q_w 350°/2 h C_a	98.3	84.3	14.5	55.5
50	17	25	30	Tr.	880° Q_w 250°/1 h C_a	54.2	34.0	30	61.8
					880° Q_w 400°/1 h C_a	56.1	42.1	32	66.4
85	21	65	36	Tr.	A	56.1	44	30.5	61
					850° Q_w 300°/2 h C_a	121.3	109.5	12	47.2
					875° Q_w 300°/2 h C_a	124.4	112	10.5	47.2
					900° Q_w 400°/2 h C_a	94.2	83.2	16	53.6
220	25	65	30	Tr.	925° Q_w 250°/2 h C_a	144.4	124	9	35.4
					900° Q_w	160.6	145	3.0	7.3
					900° Q_w 250°/2 h C_a	144.9	125	8	31.5
2	46	33	41		850° Q_w 400°/1 h C_a	96.8	67.1	16.5	37.3
2	51	24	18		875° Q_w 400°/1 h C_a	119.6	67.1	9	16
					825° Q_w 400°/1 h C_a	98.2	77.2	12	28.5
12	46	34	63	Tr.	850° Q_w 400°/1 h C_a	94.2	71.2	14	39.5
					900° Q_w 300°/2 h C_a	89.1	71.2	23	53.7
					825° Q_w 400°/1 h C_a	86.1	71.2	21	54.7
13	36	23	10	Tr.	875° Q_w 400°/2 h C_f	76.1	59.1	22.5	58.1
13	55	21	20	4	875° Q_w 400°/1 h C_a	104.0	80.3	14	35.1
					880° Q_w 400°/1 h C_a	104.7	75.1	11.5	32.5
					825° Q_w 400°/1 h C_a	98.3	78.1	17.5	51.7
					825° Q_w 400°/1 h C_a	98.3	76.2	18	49.5
22	32	66	23 (2)		843° Q_w Tp 204°	161.7	148	11.0	43.3
					843° Q_w Tp 260°	150.0	132.6	12.0	51.0
					843° Q_w Tp 316°	136.2	126.7	13.5	52.0
					843° Q_w Tp 371°	114.1	118.7	15.5	59.3
29	54	61	28 (2)		802° Q_w Tp 260°	197	181	8	34.0
					802° Q_w Tp 316°	175	160	10	40.3
					802° Q_w Tp 371°	144.4	131.5	11	43.3

Fe-U-C, U Steel (7*).—*(Continued)*

U	C	Mn	Si	V	Treatment	*UTS*	*YP*	El_a	*RA*
31	45	68	33 (2)		816° Q_w Tp 260°	176.0	158.3	10.5	42.8
					816° Q_w Tp 316°	153	141	12.5	48.1
					816° Q_w Tp 371°	132.3	120.5	14.0	54.2
152	43	55	56	Tr.	815° Q_o 300°/2 h C_a	66.1	45.0	11.5	44.6
312	47	80	80	Tr.	815° Q_o 400°/2 h C_a	130.2	107	10.5	34.7
6	63	34	64		875° Q_o 500°/2 h C	118	83.2	14	40.1
53	72	54	75		790° Q_o 300°/2 h C_a	233	197	1.5	0.7
					870°–790° Q_o 300°/2 h C_f	205	184	14	13
					870°–790° Q_o 300°/2 h C_f	202	181	14.5	19.2
					870°–790° Q_o 350°/2 h C_s	167	149.5	17.5	20.6
					850°–775° Q_o 350°/2 h C_a	154.5	128	10	31.1
					870°–790° Q_o 400°/1 h C_a	173	157.5	7	24.7
					850°–770° Q_o 400° 2 h C_a	170	126	10	31.5
					850°–770° Q_o 450° 2 h C_a	125.1	109.5	12.5	33.1
					870°–790° Q_o 500°/1 h C_a	132.2	116.5	12.5	30.1
190	63	77	75	Tr.	875° 300°/2 h C_a	189	174.8	7	22.3
					900° 300°/2 h C_a	197	148	6	18.1
					800° 400°/2 h C_a	96.2	69.1	8.5	21.6
					850° 400°/2 h C_a	130.7	117.4	10	30.8
					875° 400°/2 h C_a	130.7	92.3	11	32.5
					900° 400°/2 h C_a	132.3	120.5	9.5	30.2

* Except where noted.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bouchayer, *439*, **1923**: 557. (2) Foote, *33*, **25**: 789; 21. (3) Guillet, *74*, **1**: 506; 04. (4) Honda, *159*, **8**: 51; 19. (5) Hutchins, *Trans. First World Power Conference*, **4**: 704; 24. (6) Lamort, *139*, **11**: 225; 14. (7) Polushkin, *74*, **17**: 421; 20. (8) Tritton and Hanson, *140*, **110**: 90; 24.

Ni AND ITS ALLOYS WITH C, Cr, Cu, Fe, AND Mn

P. D. Merica

[1] Furnished by T. H. Wickenden.

MECHANICAL AND ELASTIC PROPERTIES

TABLE 1.—Ni

Standard 99% commercially pure "malleable" Ni* containing Co, 0.40; Fe, 0.40; Cu, 0.15; Mn, 0.15; C, 0.10; Si, 0.10 (5, 8, 19, 29); *v. also* references under separate items.

Shape	Trt¶	*UTS*	*YP*‡	*PL*§	El_a	*RA*
Bars	R_h	46–56	18–28	11–21	40–60††	50–70
	RA‖	42–53	14–25	11–18	40–60††	50–70
	R_c**	53–120	25–105	18–70	40–1††	50–5
Sheet or strip	RA	42–53	14–25	11–18	30–45†	
	R_c**	53–120	25–105	18–70	30–1†	
Wire	DA	42–53	14–25	11–18	20–40†	
	D_c**	53–120	25–105	18–70	20–1†	
Castings	G_s	35–49	14–21		20–35††	20–50

d_4^{20} = 8.80–8.90 (11,13,22).
Compressibility same as pure Ni (*v.* vol. III).

Trt \ Load	*BHN*, 10 mm ball 3000 kg	*BHN*, 10 mm ball 500 kg	*ScH* universal hammer	*RHN*	Elastic constants	10^3 kg/mm²	Lit.
A	90–110	70–90	8–12	35–50	*E*	20.4–21.8	(12, 15, 17, 21, 22)
R_c	110–300	90–300	12–50	50–110	*G*	7.2– 7.7	(20)
G_s	90–110	70–90	8–12		λ	0.33	(4)

* Indications of a few tests are that data apply equally well to pure Ni, but data on pure Ni are too scanty to be useful. For specific gravity *v.* p. 456; compressibility *v.* vol. III; viscosity *v.* vol. III; surface tension *v.* vol. III.
† Depends on gage of metal, larger for heavier gages.
‡ By drop of beam or at $\Delta l = \frac{1}{2}\%\ l_0$.
§ By extensometer.
‖ May be regarded as the normal or standard state.
¶ *See* p. 392.
** Ranges are large and depend on amount of cold work which varies from 5–95 % reduction of section.
†† Diam. = 0.505 in.

TABLE 2.—Ni-Cr-Fe and Ni-Fe-Cr, "Chromel," Etc. (19)

% Ni	% Cr	% Fe	Ind. No.	Trt	*UTS*	*YP*	El_a	*RA*	*BHN*	d_4^{20}
82.5	15	1*	366	R_h	74–88	42–56	25–45	50–65	175–210	8.30–8.50
77.5	20	1*	367	R_h	77–91	49–63	25–40	50–65	180–220	
61.0	12	25†	368	R_h	63–77	35–49	25–45	50–70	180–200	8.10–8.20
				G_s	35–49	28–42	2–10		130–180	

* Alloy contains also Mn, 1; C, 0.4; Si, 0.1.
† Alloy contains also Mn, 1; C, 0.5; Si, 0.5.

TABLE 3.—Ni-Cu-X

No satisfactory systematic data exist on the mechanical properties of the Ni-Cu series. The available data on certain well known commercial alloys are tabulated below.

There exist some data on Ni-Cu which indicate: (1) *E* is a linear function of % Cu. (2) Hardness is a maximum between 35 and 50% Cu, its value at the maximum being a little greater than that of pure Ni.

Ni, 68.4; Cu, 29.0; Fe, 2.0; Mn, 0.3; C, 0.2; Si, 0.1 "Monel metal" (7, 19)

Shape	Trt¶	*UTS*	*YP*‡	*PL*§	El_a	*RA*
Bars	R_h	60– 67	25– 32	18–28	35–50††	45–65
	RA‖	46– 53	18– 28	14–21	35–50††	
	R_c**	53–120	28–105	21–70	35– 1††	45–50
Sheet or strip	RA	46– 53	18– 28	14–21	30–45†	
	R_c**	53–120	28–105	21–70	30– 1†	
Wire	DA	46– 53	18– 28	14–21	20–40†	
	D_c**	53–120	28–105	21–70	20– 1†	
Castings	G_s	46– 56	21– 28		25–35††	

*†‡§‖**†† For meanings *v.* footnotes to Table 1.
d_4^{20} = 8.80–8.90.

UCS: Flattens, does not fracture.
YP_C = 42–49 ($\Delta l = -\frac{1}{2}\%\ l_0$).
PL_C = 25–32.

Trt \ Load	*BHN*, 10 mm ball 3000 kg	*BHN*, 10 mm ball 500 kg	*ScH* universal hammer	*RHN*
A	110–130	90–110	15–20	65– 75
R_h	140–160	110–130	22–28	75– 85
R_c	130–300	110–300	20–55	90–110
G_s	110–130	90–110	15–20	60– 70

$10^{-3}\ E$ = 16.8–18.3.
$10^{-3}\ G$ = 6.3–7.0.
USS (to punch sheet or shear rod) = 35–46.
TMR = 39–46.
PL_S = 14–21.
IS { Standard Izod: Specimens merely bend over.
Standard Charpy: Specimens fracture; *IS* = 14–28 kg-m.
Twist: π × diam. × no. of turns = 2.5–3.0 in. (for hot rolled alloy).

Ni, 55; Cu, 43.9; Mn, 1.00; C, 0.10 "Constantan" (7, 19)

Trt	*UTS*	*YP*	El_a	*RA*	*BHN*, 10 mm ball 3000 kg	*BHN*, 10 mm ball 500 kg	*ScH*	*RHN*
A	42–49	14–21	40–60	50–70	100–120	80–100	12–16	55–65
R_c	49–99	21–88	40– 1	50– 5	120–300	120–300	16–50	

d_4^{20} = 8.85 ± 0.05. $10^{-3}\ E$ = 14.8–16.2.

TABLE 4.—Cu-Ni, Cu-Ni-Zn, and Cu-Zn-Ni*
(Cupro-nickel, Nickel-silver, Ambrac) (2)

% composition Ni	Zn	M. P., °C	Ind. No	Hard *UTS*	Hard *YP*‡	Hard El_a	Hard *BHN*§	Soft *UTS*	Soft *YP*‡	Soft El_a	Soft *BHN*§	d_4^{20}	ρ_{20}‖
15	¶	1170†	446	49		3		32		30		8.95	21.1
20		1190†	446	60		2		35		30			
25		1220†	446					37	13	38			
20	5**	1150	136	60	53	5	160	35	15	35	70	8.84	26.6
18	17	1110†	988	67		2	158	41		33	77	8.75	30.5
30	5	1220	135	74	67	2	190	46	20	28	85		
25	20	1130†	990	77		4	208	51		30	89	8.72	43.1
30	23	1140†	991	91		2		51		35		8.74	48.2
10	25	1010†	985	63		3		35		45		8.66	
15	21	1080†	987	63		5		35		40			
15	28	1030†	987	67		2		39		35			
18	27	1055†	988	77		1		42		40		8.66	29.9

* For annealing ranges, *v.* Table 14.
† (28).
‡ Stress at which $\Delta l = \frac{1}{2}\%\ l_0$.
§ 10 mm, 500 kg.
‖ Electrical resistivity, microhm-cm.
¶ $E = 8.4 \times 10^3$ kg/mm².
** $E = 13.4 \times 10^3$ kg/mm².

TABLE 5.—Tensile Properties and Hardness of Ni-Fe Alloys (9, 25) *v. also* Table 12

These alloys made out of 99.97% pure electrolytic Fe and electrolytic Ni. Analyses showed: C well under 0.01%, S, Si, P and Mn negligible.

A charge of electrolytic Fe was melted into an ingot and forged under same conditions employed in preparation of alloys. Analysis of this gave: C, 0.047; Mn, 0.0; Si, 0.062; P, 0.016; S, 0.005.

All except last three compositions were annealed at 900°C.

% Ni	*UTS*	*YP*	El_a	*RA*	*ScH*
0.25	35.4	26.7	35.0	69.7	14.5
0.50	39.0	28.5	36.5	70.2	14
1.00	42.1	30.8	33.7	68.8	14
2.00	45.3	34.3	34.2	65.4	14
3.00	49.7	38.9	27.5	67.6	14.5
4.00	49.3	36.6	28.4	66.7	14

TABLE 5.—TENSILE PROPERTIES AND HARDNESS OF NI-FE ALLOYS ([9, 25]) *v. also* Table 12.—(*Continued*)

% Ni	*UTS*	*YP*	El_a	*RA*	*ScH*
5.00	51.5	41.0	31.4	68.1	15.5
6.00	52.9	39.7	29.5	64.2	
7.00	51.3	40.9	26.7	58.5	16
8.00	55.2	44.5	30.2	64.4	16
9.00	63.2	50.7	25.1	60.2	17
10.0	62.8	50.5	22.3	59.1	18
10.5	62.9	48.6	24.2	57.2	20
11.0	85.6	69.7	11.6	34.6	21
12.0	85.6	68.7	14.5	35.8	25
13.0	113.4	90.0	6.8	18.2	31.5
15.0	107.8	88.8	10.5	35.8	34
18.0	127.7	96.8	10.0	34.4	34
19.0	127.0	81.7	10.7	38.7	31
20.0	87.8	78.0	21.5	62.5	34.5
21.0	136.2	86.2	4.0	4.2	31
25	73.3	39.6	45.0	68.3	21
45	57.6	38.4	32.5	65.0	17
50	76.3	53.2	26.5	63.7	

TABLE 6.—COMPRESSION TESTS ON NI-FE ALLOYS* ([18])

% Ni	% C	% Mn	% Si	EL_C	ε†
0.27	0.19	0.79	0.31	35	50
0.51	.14	.75	.20	35	50
0.95	.13	.72	.23	32	49
1.92	.14	.72	.21	43	47
3.82	.19	.65	.20	44	41
5.81	.18	.65	.31	63	37
7.65	.17	.68	.28	63	33
9.51	.16	.86	.20	110	3
11.39	.18	.93	.22	158	1
15.48	.23	.93	.24	126	1
19.64	.19	.93	.27	126	3
24.51	.16	1.00	.30	79	16
29.07	.14	0.86	.38	38	41

* Specimens 1 in. × 0.798 in. diam. (forged, unannealed).

† $\epsilon = -100 \frac{\Delta l}{l_0}$ for 158 kg/mm² load.

TABLE 7.—ELASTIC PROPERTIES OF NI-FE AND NI-FE-CR ALLOYS ([10, 17])

% Ni	$10^{-3}E$	% Ni	$10^{-3}E$	% Ni	$10^{-3}E$	% Ni	% Cr	$10^{-3}E$
5.0	21.7	27.9	18.1	39.4	15.1	12.2	1	19.0
15.0	19.1	30.4	16.0	44.3	16.3	16.2	2.5	19.6
19.0	17.7	31.4	15.5	70.0	19.8	16.8	1	18.3
24.1*	19.3	34.6	15.4	100.0	21.6	34.8	1.5	15.5
24.1†	17.4	35.2	14.9			35.7	1.7	15.7
26.2	18.5	37.2	14.6			36.4	0.9	15.7

* Non-magnetic.

† Magnetic, transformation probably incomplete.

TABLE 8.—DENSITY (gm/cm³) OF NI-FE ALLOYS* ([7])

% Ni	0	10	20	30	40	50	60	70	80	90	100
100 *d*	787.5	789	802	806	763?	805	829	839	852	860	886

* Fairly pure Ni-Fe.

TABLE 9.—TENSILE, HARDNESS AND IMPACT TESTS ON NI-STEELS (NI <6%)*

Treatment	*UTS*	E = *EL*† P = *PL* Y = *YP*	El_a	*RA*	*BHN*	*IS*‡‖, kg-m per cm²
Ni, 1.76; C, 0.26; Mn, 0.90; Si, 0.18; S, 0.02; P, 0.04 ([14])						
G_s W 800°/4 h C_a 1 h	67.5	39.4 E	15§	14		5.1_v
Same, Tp 700°/1 h C 6 h	61.0	36.9 E	21	22.5		7.5_v
G_s W 800°/4 h C_f 18 h	64.8	36.6 E	28.5	39.8		8.2_v
Same, Tp 700°/1 h C 6 h	64.5	37.0 E	33	52.8		33_v

TABLE 9.—TENSILE, HARDNESS AND IMPACT TESTS ON NI-STEELS (NI <6%).*—(*Continued*)

Treatment	*UTS*	E = *EL*† P = *PL* Y = *YP*	El_a	*RA*	*BHN*	*IS*,‡ kg-m
Ni, 2.73; C, 0.37; Mn, 0.54; Si, 0.18; S, 0.02; P, 0.015; Cu, 0.042 ([23])¶						
G_c A** tangential	56.9	34.3 Y	19.4	29.0		1.87_v
G_c A** longitudinal	56.8	34.6 Y	21.0	23.9		2.34_v
G_c F_m tangential	66.2	38.7 Y	21.8	44.7		2.90_v
G_c F_m longitudinal	66.3	38.2 Y	23.6	49.8		2.67_v
G_c F Trt†† tangential	62.4	45.2 Y	25.5	64.6		4.36_v
G_c F Trt†† longitudinal	64.3	45.5 Y	26.2	65.7		3.51_v
G_c Trt†† tangential	59.2	41.1 Y	24.2	48.9		2.98_v
G_c Trt†† longitudinal	64.3	46.9 Y	24.7	53.2		2.74_v
Ni, 2.30; C, 0.44; Mn, 0.43; Si, 0.48; S, 0.016; P, 0.017; Cu, 0.062 ([23])¶						
G_c A** tangential	65.3	39.2 Y	12.1	14.2		0.69_v
G_c A** longitudinal	65.7	39.7 Y	12.0	13.2		0.74_v
Ni, 3.59; C, 0.20; Mn, 0.69; Si, 0.18; P, 0.007; S, 0.013 ([27])						
A (0.505 in. diam.)	55.5	39 E	31.0	64.7	143	10.42_u
843° Q_o Tp (½ in. diam.) 100°	138	112 E	12.5	41.5	354	6.78_u
205°	136	102 E	11.0	45.6	356	6.42_u
427°	105	88 E	15.5	68	264	9.74_u
538°	81	67 E	20.3	73	216	11.46_u
Ni, 3.35–3.70; C, 0.30–0.37; Mn, 0.57–0.70; P, 0.008–0.04; S, 0.020–0.045 ([3, 6, 24, 29])						
A (⅝–1.5 in. diam.)	55 – 69.5	39 – 42‡‡	31 –26.5	56–55	160–170	
788–860° Q_w Tp 650°	76 – 81.5	59 – 67.5	26.5–22	69–60	200–225	
600°	84 – 91	71 – 77	23.5–20	67–60	226–248	
500°	96 –112.5	85 – 99	20 –17	61–57	290–302	
400°	118 –134	105 –119	15 –12	57–50	340–360	
300°	146 –156	129 –135	13 –12	54–48	370–444	
Ni, 3.70; C, 0.36; Mn, 0.73; Si, 0.15; P, 0.007; S, 0.011 ([27])						
843° Q_o Tp 427°	130	120	14.5	61.2	342	11.1_u
	155	141	12.0	57.5	429	4.6_u
Ni, 4.6–5.3; C, 0.12–0.17; Mn, 0.30–0.62; P, 0.008–0.046; S, 0.018–0.045 ([92])						
A	50.5– 59	35 – 41‡‡	34 –25.5	60–48	149–170	10.7_u 10.5_v
760–900° Q_o Tp 650°	62 – 77	41 – 66	34 –22.5	71–66	172–217	
600°	64 – 82	43.5– 72	32.5–22	70–62	180–230	13.8_u 16.2_v
500°	74.5– 93	55 – 81	28 –18	70–58	215–260	
400°	91 –115	72 – 93	23 –14	68–47	257–318	
100°	121 –135	96 –112	15 –11.5	55–38	330–365	3.6_u 4.5_v
						ScH
Ni, 3.31–3.75; C, 0.15–0.20; Mn, 0.34–0.60; P, 0.006–0.023; S, 0.025–0.033 ([3, 29])						
A (1–1.5 in. diam.)	50.5– 56	31.5– 48‡‡	35 –32	65–52	126–145	22–26
802–848° Q_o Tp 650°	53 – 57.5	33 – 42.5	33 –28	76–67	150–178	26–31
600°	55 – 67	37 – 47	32 –26	73–68	170–200	29–34
500°	65 – 86	48 – 66	27 –22	68–62	187–277	38–47
400°	79.5– 97	60 – 82	22.5–15	65–53	190–325	43–48
300°	83 –115	60.5– 93	22 –13	59–48	192–358	46–53
Ni, 3.16–3.65; C, 0.35–0.39; Mn, 0.48–0.65; Si, 0.10–0.22; P, 0.009–0.041; S, 0.020–0.036 ([3, 6, 28, 29])						
A (1–1.5 in. diam.)	67 – 70	42– 43.5‡‡	28 –25	56–48	183–200	26–35
773–860° Q_o Tp 650°	73 – 81	43– 68	28 –22	67–62	217–230	34–41
600°	74.5– 88	51– 72	28 –21	65–62	229–244	36–42
500°	86.5–101	76– 88	20 –17	60–54	265–296	48–52
400°	109 –134	91–112	16 –12.5	50–47	325–349	57–62
300°	135 –165	112–151	13 –11	45–43	385–420	65–67

* The average effect of Ni up to 8 % upon an Fe-C alloy in the fully annealed condition is as follows: 0.01 % Ni increases *EL* by 28 g/mm², *UTS* by 29.5 g/mm², *RA* by 0.005 %, decreases *El* by 0.010 % ([1]).

† Some data not clear as to whether *PL*, *EL*, or *YP* is measured.

‡ Subscripts to values of *IS*: u = Izod machine, v = Charpy machine.

§ Specimens 50 mm × 13.8 mm diam.

‖ Specimens 30 mm sq. × 160 mm long, notch 2 mm radius.

¶ Taken from ring-casting 71.5 in. long by 10.9 in. diam.

** A = A 950°/4 h C_a, W 600°/6 h.

†† Trt = 800°/1 h Q_w Tp 675°.

‡‡ Data not clear as to method, lower figure generally reported as *EL*, higher as *YP*.

TABLE 10.—TORSION TESTS ON NI-STEELS ([27])

Treatment (in 1 in. diam.)	UTS	EL	El_a*	RA	TMR	EL_8	Tw (°/cm)	$\frac{TMR}{UTS}$	$\frac{EL_8}{EL}$
Ni, 3.48; C, 0.19; Mn, 0.70; Si, 0.10; P, 0,009; S, 0.019									
843° Q_o Tp 205°	85.7	58.7	17.0	56.7	81.7	28.6	35.9	97	48
	90.3	60.8	16.5	47.4	88.9	28.6	28.7		
843° Q_o Tp 150°	92.9	65.3	16.5	49.1	89.1	28.6	32.0	98	45
	88.2	62.5	17.0	53.5	88.6	28.6	42.8		
A..........	53.2	34.4	23.5	67.0	51.9	21.4	64.3	99	67
	52.2	35.1	23.0	65.1	53.3	25.2	51.9		
K (1/32) 815° Q_o Tp 315°	83.1	63.2	18.0	63.7	76.7	34.8	7.9	96	55
	83.3	63.2	17.5	63.5	79.4	34.0	8.5		
Ni, 3.66; C, 0.30; Mn, 0.70; Si, 0.18; P, 0.011; S, 0.010									
845° Q_o Tp 650°	80.1	61.1	19.5	66.0	69.9	39.4	54.5	90	69
	77.3	60.4	21.0	67.5	69.8	43.0	63.4		
845° Q_o Tp 425°	92.8	71.7	16.5	59.2	80.8	45.9	79.6	87	64
	93.3	72.7	18.0	58.2	81.2	46.5	76.8		
A..........	65.4	36.2	18.5	50.7	60.8	17.9	39.4	93	47
A†.........	64.5	35.5	15.0	52.7	58.9	16.2	39.6		

* Diam. = 0.505 in. † Broke near end.

TABLE 11.—EFFECT OF HEAT TREATMENT ON IMPACT STRENGTH OF NI-STEELS ([3])

Composition A = **Ni, 2.9; C, 0.17**; Mn, 0.34; Si, 0.05; P, 0.023; S, 0.033.

Composition B = **Ni, 3.65; C, 0.37**; Mn, 0.65; Si, 0.17; P, 0.030; S, 0.020.

Composition C = **Ni, 6.00; C, 0.17**; Mn, 0.34; Si, 0.39; P, 0.014; S, 0.014.

Treatment		Composition A		Composition B		Composition C	
		IS Izod	IS Charpy	IS Izod	IS Charpy	IS Izod	IS Charpy
N 860°..........		12.3	14.7	5.0	4.5	10.7	10.5
860° Q_w.........		4.0	3.9	0.6	0.8	4.3	4.6
Same, Tp..	300°	4.8	5.8	0.6	1.0	4.6	4.5
	400°	7.5	7.2	1.1	1.3	6.6	5.9
	500°	10.4	11.7	7.2	8.0	9.4	10.9
	600°	14.3	16.7	10.0	13.0	13.7	15.2
	650°	15.6	20.4	11.2	14.3	14.1	15.2
	700°					9.8	10.6
	725°					8.6	9.8
860° Q_o..........		8.9	10.1	0.8	1.0	3.6	4.5
Same, Tp..	300°	10.2	12.9	0.7	0.8		
	400°	11.6	14.5	1.5	2.0		
	500°	13.3	16.8	6.9	8.7		
	600°	14.5	18.2	10.1	12.3	13.8	16.2
	650°	15.1	20.4	11.3	13.6		

For Ni, 3.5; C, 0.17 (845° Q_o 760° Q_o Tp 232°) IS (Izod) = 4.8.
For Ni, 5; C, 0.16 (845° Q_o 730° Q_o Tp 232°) IS (Izod) = 10.5.

TABLE 12.—HIGH NI-STEELS

% composition Ni	C	Mn	Trt	UTS	YP	El_a	RA	Lit.
25–28	0.30			60–65	25–35	30–35	50–60	([6])
30–35	to			60–67	28–35	30–40	40–60	([6])
35–38	0.50			70–81	45–55	25–35	50	([6])
26	0.20	1.50	R_h	55.2	8.4	50	71	([8])
30	0.15	1.50	A*	59.4	19.7	47	69	([8])
32.3	0.12	2.30	A*	54.5	15.5	43	66	([8])
35.1	0.22	1.50	A*	59.7	21.1	42	67	([8])
36	0.08	0.50	A*	50.9	16.9	39	68	([8])
45	0.37	1.50	A*	66.4	24.6	44	51	([8])
50.7	0.17	1.25	R_h	69.6	34.1	39	68	([8])

* Annealed from above 790°C.

Data on hardness of Ni-Fe alloys are unsatisfactory.

Approximate values are, for Ni, 10–20%: BHN = 200–350, ScH = 20–35; for Ni, 28–60%: BHN = 160–190, ScH = 16–24.

For Ni, 60–100%, hardness decreases continuously to that for pure Ni.

TABLE 13.—NI-MN ALLOYS* ([7, 19])

% composition Mn	C	Fe	Si	S	UTS	YP	PL	El_a	RA
3.00	0.06	0.62	0.22	0.018	52.1	16.5	14.1	51	60
3.58	.06	.62	.23	.018	52.3	16.7	15.8	50	62
4.40	.06	.73	.27	.021	53.1	19.3	17.6	43	63
5.06	.06	.72	.28	.020	54.5	18.8	15.8	48	62
6.78	.07	.89	.34	.020	57.6	21.8	21.4	50	66
6.84	.08	.91	.35	.020	57.1	22.1	21.9	36	50
9.18	.10	.95	.42	.021	59.1	23.1	22.5	48	62
9.24	.10	.94	.41	.020	58.9	23.0	21.8	48	64

* For alloys of the typical composition: Mn, 0.3 to 10; Fe, 0.4; Co, 0.4; C, 0.1; Si, 0.1 the values of UTS, YP, and PL increase approximately 0.7 kg/mm² for each additional 1 % Mn, while El and RA are not changed appreciably. Although no data are available, the other properties may be accepted as substantially the same as for 99 % nickel if Mn content is not over 10 %. Alloys containing 2–6 % Mn have tensile properties practically identical with those of Ni containing 0.3 % Mn. These are commercially known as high Mn nickel, spark plug wire nickel, magno-nickel, etc.

THERMAL PROPERTIES

Mold shrinkage = 2% of length for Ni, "Chromel," "Monel metal," and "Constantan" ([5, 7, 19, 29]).

TABLE 14.—ANNEALING AND FORGING RANGES ([5, 7, 19, 29])

Metal	Ni	"Chromel"	"Monel metal"	"Constantan"
Annealing range, °C.......	500–700	600– 925	500– 700	500– 700
Forging range, °C.........	975–1200	975–1150	975–1150	925–1100

ANNEALING RANGES OF NICKEL SILVERS (CU-NI-ZN) ([2])

% Ni	% Zn	Ind. No.	Annealing range, °C	% Ni	% Zn	Ind. No.	Annealing range, °C
15	0	446	600–800	30	5	135	650–800
20	0	446	600–800	25	20	990	550–800
25	0	446	650–800	30	23	991	600–800
20	5	136	650–800	10	25	985	550–800
18	17	988	600–800	18	27	998	550–800

Annealing range depends on time and previous treatment, especially cold work. Ranges given above for Ni and Monel metal are the active annealing (softening) ranges. For R_h or mildly R_c metal: A 800–900°C; while for R_c over 20%: A 700–800°. Neither Ni nor Monel metal is subject to heat treatment in the usual sense.

LITERATURE

(For key to the periodicals see end of volume)

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TABLE 15.—CRITICAL RANGES OF NI-STEELS

% composition						Heating rate, °/sec		Ac1, °C			Ac2 Max.	Ac3, °C		Cooling rate, °/sec	Ar3, °C		Ar1, °C			Lit.
Ni	C	Mn	Si	P	S	Range	Av.	Beg.	Max.	End		Max.	End		Beg.	Max.	Beg.	Max.	End	
0.00	0.40	0.00	0.008	0.00	0.00	0.09–0.21	0.15	733	736	746	767	788	809	0.16	767	745	708	704	694	(26)
.00	.40	.75	.22	.014	.022	0.075–0.30	.16	726	732	748	759	783	802	.14	743	729	681	672	654	
2.00	.38	.66	.16	.017	.011	0.10–0.23	.15	696	710	723		738	758	.16	691	670	642	630	599	(26)
2.04	.35	.65	.17	.010	.020	0.044–0.19	.12	699	709	721		742	758	.13	697	678	644	634	608	
2.68	.35	.64	.24	.014	.022	0.10–0.30	.19	691	704	716		737	758	.18	672	654	621	611	576	(26)
2.90	.40	.63	.28	.023	.033	0.16–0.20	.18	686	701	714		726	743	.19	670	644	617	606	572	
3.00	.37	.71	.22	.012	.010	0.11–0.26	.19	688	703	717		729	750	.18	668	641	616	609	567	(26)
3.46	.29	.56	.28	.018	.028	0.052–0.16	.096	684	695	710		730	750	.074	677	648	610	598	576	
3.31–3.75	.15–.20	.34–.60		.006–.023	.025–.033	Case (0.80 C)		678–701 (max.)			722–738	732–794 (max.)					583–631 (max.)			(3, 29)
3.35–3.70	.30–.37	.57–.70		.008–.04	.020–.045			677–710 (max.)			710–745	710–745 (max.)					584–610 (max.)			(3, 6, 24, 29)
3.16–3.65	.35–.39	.48–.65	0.10–0.22	.009–.041	.020–.036			699–707 (max.)			716–729	716–729 (max.)					588–592 (max.)			(3, 6, 29)
4.61–5.32	.12–.17	.30–.62		.008–.046	.018–.045			670–692 (max.) Same, for case			713–725	740–760 (max.)					555–576 (max.)			(29)

MECHANICAL AND THERMAL PROPERTIES OF CAST IRON AND OF STEELS CONTAINING C, CR, CR-V, CU, NI-CR, NI-CU, NI-V AND V

W. H. HATFIELD, J. WOOLMAN AND O. PRIEST

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INTRODUCTION

Order of Accuracy of Results Quoted.—The term "order of accuracy" refers to the variations which are likely to arise from the method of testing *per se*. These variations may be due to slight changes in the apparatus, to the limits within which the observations may be read, to the sensitiveness of the apparatus, and to personal error. These do not affect the results in the same way, some giving a constant error and others a proportionate error.

Variability of Results.—It has not been possible to quote results with the order of accuracy attainable for the various tests. Variations in data arise not so much from errors of observation, but rather from slight differences in composition or small differences in heat treatment. Differences in heat treatment may be due to errors in temperature measurement or to varying rates of cooling. The size of the sample treated is in many cases of utmost importance. In the data given all test pieces, except where otherwise stated or indicated, were treated in the form of bars of about 1.5 in. diameter or of square section. Other variations in the rate of cooling may be due to the following causes:

In water quenching, to the temperature of the water.

In oil quenching, to different oils used, to their temperature and condition.

In air cooling, to the conditions of the atmosphere (temperature and nature of the draughts).

In furnace or slow cooling, to differences in the lagging.

In consequence of such possible variations, results by different observers on the same type of material often vary by considerable amounts, and for the same reasons in applying the results, one has to bear in mind the variations that may occur due to the above causes. The order of accuracy of the determinations and the variability of the results are tabulated below. The latter are quoted with a certain amount of reserve, but in most cases may be depended on as being of the right order. The term "Variability of Results" is not intended to apply to those cases of brittle steels where the test piece breaks prematurely.

Accuracy and Variability of Results

ϵ = Probable order of accuracy of determination.
η = Approximate variability of results.

Property	$\pm\epsilon$	$\pm\eta$
UTS, UCS	½%	5 kg/mm²
YP, YP$_C$	1%	5 kg/mm²
PL, EL	5%	10 kg/mm²
PL$_C$*, EL*$_C$	2%	10 kg/mm²
EL, RA	2	4
USS	1%	
TMR	1%	5 kg/mm²
YP$_S$	2%	7 kg/mm²
PL$_S$*, EL*$_S$	5%	10 kg/mm²
Tw	1%	
E, G	2%	2%
BHN, LCH	1%	5%
ScH	5%	5%
d_4^{20}	0.1%	0.5%
k	2%	4%
C	2%	2%

Torsion Test Data.—The *maximum shearing strength* is obtained from tests on hollow specimens. In other cases, it has been calculated from results obtained on solid test pieces on the assumption that at the breaking point, the stresses are uniform across the section.

Bend Tests on Cast Iron.—Owing to the nature of this material, results of tests are very erratic, and the results quoted can only be taken as typical of the corresponding analysis.

Impact Tests.—In all cases, the actual energy to fracture the test piece is given. In the case of many observers, the results are quoted in energy units per unit area at the notch, but as results on different sizes of test pieces are not strictly comparable, nothing is gained by so reducing the results.

The different types of test pieces are indicated by subscripts, for meaning of which *see* p. 396.

Approximate Variability of Results.—Considerable variations are obtained, in many cases even in the same test piece, on material of similar composition and heat treatment. It is difficult, therefore, to give an estimate of the reliability of application in this case. The values quoted are, however, typical of the results to be obtained.

Physical Data.—*Specific Gravity.*—With great care in observation, density measurements can be made to an accuracy of below 0.01 %. It would appear, however, that most of the data available have been determined with an accuracy not greater than 0.1 %.

Table 1.—Chemical Analyses

The analysis quoted for any given material, refers in most cases to the type of that material, and the range of composition covering that type has been given. It is to be understood that the actual amounts of any element may vary within small limits from the value quoted. In many cases where little published work is available, the actual analysis of the steel has been given.

Carbon Steels

All these steels contain traces of S and P

Key No.	% composition C	Mn	Si	Ind. No.
1	<0.07	0–0.2	Tr.	
2	0.08	0.4–0.6	Tr.	
3	0.09	0.1–0.4	Tr.	
4	0.14	0.1–0.3	0–0.3	
5	0.14	0.3–0.7	0–0.3	341

Carbon Steels.—(*Continued*)

Key No.	% composition C	Mn	Si	Ind. No.
6	0.18	0.7–0.8	0.1–0.2	341
7	0.18	0.1–0.6	0–0.4	
8	0.23	0.4–0.6	0.3	
9	0.25	0.4–0.6	Tr.	
10	0.25	0.1–0.2	Tr.	
11	0.28	0.17–0.26	0.03–0.04	
12	0.28	0.75–0.95	0.35	
13	0.30	0.4–0.6	0.10–0.3	
14	0.32	0.4–0.6	<0.3	
15	0.32	0.7–0.8	<0.4	
16	0.35	<0.4	0.15	
17	0.37	0.71	0.19	
18	0.38	0.2–0.25	<0.1	
19	0.38	0.4–0.6	<0.2	
20	0.40	0.43	0.33	
21	0.44	0.1–0.3	0.03–0.07	
22	0.44	0.46	0.275	
23	0.44	0.49	0.052	
24	0.45	0.7–0.9	0.12	
25	0.45	0.7–0.8	0.3–0.4	
26	0.45	0.35	0.65	
27	0.48	0.4–0.6	0.12–0.15	
28*	0.48	0.8–0.9	0.06–0.1	
29	0.49	0.1–0.2	<0.10	
30	0.49	0.70	0.34	
31	0.50	0.43	0.24	
32*	0.52	0.5–0.7	0.2–0.3	
33	0.53	0.48	0.12	
34	0.54	0.1–0.2	0.03–0.08	
35	0.55	0.8–0.9	0.2–0.3	
36	0.55	0.44	0.86	
37	0.58	0.1–0.3	<0.2	
38	0.59	0.4–0.6	<0.49	
39†	0.60	0.7–0.8	0.20	
40	0.63	0.8–0.9	0.1–0.2	
41	0.63	0.4–0.65	<0.3	
42	0.64	0.18	0.336	
43	0.65	0.26	<0.06	
44	0.65	0.48	0.08	
45	0.67	0.66	0.07	
46	0.70	0.12–0.26	<0.3	
47	0.71	0.67	0.147	
48‡	0.73	0.74	0.313	
49	0.75	0.1–0.35	<0.100	
50§	0.78	0.71	0.322	
51	0.79	0.2–0.4	<0.38	
52	0.81	0.87	0.22	
53	0.84	<0.3	<0.3	
54	0.84	0.5–0.65	<0.2	
55	0.86	0.07	0.056	
56	0.87	0.7–0.8	0.06–0.07	
57	0.89	0.19	0.34	
58	0.90	0.3–0.5	<0.3	
59	0.93	0.45–0.6	<0.3	
60	0.94	0.2–0.4	<0.3	
61	0.98	0.43	0.158	
62	1.00	0.4–0.6	0.5	
63	1.00	0.2–0.35	<0.2	
64	1.02	0.2–0.4	<0.3	
65	1.10	0.35	0.059	
66	1.11	0.23	0.27	

Carbon Steels.—(*Continued*)

Key No.	% composition C	Mn	Si	Ind. No.
67	1.18	0.050	0.094	
68	1.20	0.2–0.44	0.2–0.3	
69	1.22	0.1–0.3	<0.2	
70	1.25	0.62	0.46	
71	1.26			
72	1.28	0.8	0.06	
73	1.29	0.22	0.31	
74	1.30	0.3–0.4	<0.1	
75	1.35	0.54	0.26	
76	1.40	0.2–0.45	Up to 0.2	
77	1.50	0.64		
78	1.50	0.2–0.3	0.1–0.2	
79	1.60	0.55	0.085	
80	1.70	0.29	0.08	
81	1.76	0.07	0.058	
82	1.95	0.02	0.034	
83	2.10	0.58	0.078	

* Rails.
† Tram rails.
‡ R. R. tire.
§ Tram tire.

Cast Iron

Key No.	10 × % composition Total C	Graphite	Mn	Si	S	P	Ind. No.
84	23	9–11		20–25		18–22	
85	24	13		20		29	
86	24–25	9–10		10–16		17–20	
87	25	19	3	10	Tr.	3.0	
88	26–27	14–16		20–23		10–11	
89	27	8.5		20	4.5		
90	27–29	16–20		11–14		<12	
91	27–29	16–18		20–24	<1.8	<5	
92	29–30	4–7		12–15	<1.5		
93	29	24	5	29	1.5	1.8	
94	29	29	5	15		Tr.	
95	30–31	2.5–4.5		6–8	<1.0		
96	29–31	17–21		8–19	1.1		
97	30–31	26–28	6–10	15–23			
98	31	11	20	10			
99	32	15		13.5	0.5		
100	30–32	21–24	4–8	13–20	1–2	1–9	
101	28–35		<1.5	6–8	<3.5	<2	837
102	28–35		<4	6–8	<0.7	<2	836
103	32	Tr.		4	Tr.	Tr.	1477
104	32	11	3.5	8			
105	30–32	23–24	20–22	17–24			
106	30–33	27	2–9	11–20	1–2	<15	
107	32–33	27–29	5–7	22–27	1.0	2–8	
108	32–34	20–25	0–9	10–14	0.5–1.7	4–8	
109	33–34	25–26	5–6	20–22	1–1.3	8–11	661
110	33.5	29–30	6	24–28	1.0	2.0	
111	34–35	27–29	6	14–15	<1.4	1–4	
112	34–35	28–31	6–7	19–25	<1.5	1.5–5.5	
113	35	33	6.5	22–26	<1.0	3–5	
114	36–36.5	29–30	6–9	12–15	1–1.6	1–4	
115	36.5	35	5	29	6.2	13	
116	37.5	27.3	5	16	1.0	4.9	
117*	35–38	30–32	6–7	5–6	2–2.2	3.4–3.7	
118	35–38	32–33	8	13–15	1.4–1.9	1.3–1.6	
119	45.7						

* Chilled iron car wheels.

Chromium Steels

Analyses show traces of S and P in all these Cr steels excepting Nos. 146, 170, 184, 185, 189, 191.

Key No.	% composition Cr	C	Mn	Si	Ind. No.
120	0.25	0.36	0.34	0.15	
121	0.35	1.46	0.2	0.13	
122	0.5	0.36	0.32	0.19	
123	0.6	0.64	0.10	0.04	
124	0.6	0.86	0.03	0.24	
125	0.70	0.04	Tr.	0.97	
126	0.76	0.35	0.3	0.15	
127	0.9	0.47	0.72		
128	1.0	0.34	0.32	0.05	
129	1.0	0.6			
130	1.0	0.84	0.1	0.06	
131	1.0	0.97	0.24	0.22	
132	1.2	0.06	Tr.	0.7	
133	1.3	0.45	0.72	0.12	
134	1.3	0.75	0.34	0.16	
135	1.4	0.31	0.75	0.14	
136	1.5	0.35	0.25	0.1	
137	2.0	0.22	0.2	Tr.	
138	2.0	0.33	0.2	0.05	
139	2.0	0.50	0.24	Tr.	
140	2.0	0.65	0.2	Tr.	
141	2.0	0.95	0.2	0.18	
142	2.35	0.83	0.35	0.2	1137
143	2.6	0.39	0.18	0.07	
144	2.7	0.25	0.2	0.05	
145	3.0	0.4	0.2	0.1	
146	3.0	0.6			
147	4.0	0.31	0.2	0.2	
148	4.0	0.40	0.2	0.08	
149	4.0	1.00	0.1	0.22	
150	4.5	0.21	Tr.	0.23	
151	4.6	0.79	Tr.	0.42	
152	5.0	0.34	0.43	Tr.	
153	5.0	0.46	0.18	0.11	
154	5.0	0.83	0.10	0.08	
155	5.0	1.07	0.21	0.19	
156	5.4	0.25	0.19	0.19	
157	5.8	0.57	0.22	0.12	
158	6.3	0.26	0.16	0.20	
159	6.3	0.40	0.3	0.25	
160	6.3	0.54		0.14	1444
161	6.3	1.00	0.14	0.3	1444
162	7.3	0.84	0.06	0.41	
163	7.8	0.07	Tr.	0.12	
164	8.1	0.43	0.25	0.43	
165	8.1	1.02	0.1	0.37	
166	9.1	0.14	Tr.	0.34	
167	9.4	0.75	Tr.	0.88	
168	9.5	0.44		0.24	
169	9.5	1.09	0.1	0.45	
170	10	0.6			
171	10.15	0.15	Tr.	0.2	
172	10.15	0.85	<0.1	0.11	
173	10.4	0.37	0.19	0.50	
174	10.4	1.14	0.07	0.46	
175	11.2	0.36		0.16	1443
176	11.8	1.01	0.28	0.06	
177	12–14	0.08	0.1		1323

Chromium Steels.—(*Continued*)

Key No.	% composition				Ind. No.
	Cr	C	Mn	Si	
178	12–14	0.12	0.13	0.16	
179	12–14	0.28	0.22	0.1	1324
180	12–14	0.34	0.24	0.5	
181	12–14	0.39	0.24	0.5	
182	12–14	0.12	0.26	1.31	1324
183	12–14	0.32	0.22	1.19	
184	12–14	1.18		0.1	1443
185	15.0	0.6			
186	15.0	0.88	<0.1	0.03	
187	16.0	0.47	0.64	0.24	
188	19.5	0.85	<0.1	0.1	
189	20	0.6			
190	23.7	0.85	<0.1	0.20	
191	29.5				507

Chrome Vanadium Steels

Key No.	% composition							Ind. No.
	Cr	V	C	Mn	Si	S	P	
192	0.30	0.11	0.20	0.25	Tr.	Tr.	Tr.	
193	0.5	0.15	0.72					
194	0.6	0.16	0.23	0.36	Tr.	Tr.	Tr.	
195*	0.9	0.17	0.35	0.78		Tr.	Tr.	
196	1.0	0.17	0.22	0.29	0.1	Tr.	Tr.	
197	1.0	0.17	0.37	0.74	0.21	Tr.	Tr.	
198	1.0	0.19	0.44	0.84	0.17	Tr.	Tr.	
199	1.1	0.17	0.30	0.39	0.06			
200	1.3	0.19	0.38	0.47	0.06	Tr.	Tr.	
201	1.2–1.4	0.16–0.20	0.37–0.42	0.60–0.85	<0.3	<0.05	<0.05	
202	1.45	0.19	0.46	0.45	0.18			
203	1.5	0.33	0.46	0.64	0.19	Tr.	Tr.	

* Connecting rod.

Copper Steels

Analyses show traces of S in all these excepting Nos. 217, 219, 223, 235–237, 239, 240.

Key No.	% composition					Ind. No.
	Cu	C	Mn	Si	P	
204	0.1	0.78	0.52	0.07	Tr.	
205	0.2	0.13	0.50	0.25	Tr.	
206	0.2	0.30	0.30	0.26	0.08	
207	0.2	0.49	0.43	0.07	Tr.	
208	0.2	0.50	0.02	0.07	0.20	
209	0.2	0.50	0.79	0.27	Tr.	
210	0.3	0.72	0.83	0.03	Tr.	
211	0.4	0.29	0.34	0.26	0.08	
212	0.4	0.49	0.46	0.08	Tr.	
213	0.4	0.72	0.46	0.05	Tr.	
214	0.5	0.16	0.09	0.22	Tr.	
215	0.5	0.39	0.14	0.32	Tr.	
216	0.5	0.42	0.93	0.06	0.07	
217	0.5	0.57	0.02	0.31		
218	0.5	0.97	0.49	0.18	Tr.	
219	0.5	1.03	0.06	0.32		
220	0.6	0.28	0.30	0.21	0.07	
221	0.6	0.52	0.43	0.07	Tr.	
222	0.7	0.28	0.26	0.27	Tr.	
223	0.85	0.10				
224	0.9	0.48	0.7	0.07	Tr.	
225	1.0	0.16	0.07	0.21	Tr.	
226	1.0	0.40	0.16	0.31	Tr.	
227	1.0	0.54	0.32	<0.26	Tr.	
228	1.0	1.00	0.30	0.29	Tr.	
229	1.3	0.32	0.64	Tr.	Tr.	
230	1.6	0.68	0.36	Tr.	Tr.	
231	1.8	0.10	0.08	0.04	Tr.	

Copper Steels.—(*Continued*)

Key. No.	% composition					Ind. No.
	Cu	C	Mn	Si	P	
232	2.0	0.17	0.11	0.21	Tr.	
233	2.0	0.29	0.68	0.08	0.08	
234	2.0	0.39	0.18	0.24	Tr.	
235	2.1	0.22				
236	2.5	0.59	0.32	0.07		
237	2.9	0.17	1.04	0.15		
238	3.0	1.07	0.31	0.34	Tr.	
239	3.7	0.04	0.16			
240	3.7	0.38				
241	4.0	0.16	0.11	0.19	Tr.	
242	4.0	0.37	0.14	0.22	Tr.	

Nickel Chromium Steels

All these Ni-Cr steels contain traces of P and S.

Key No.	% composition					Ind. No.
	Ni	Cr	C	Mn	Si	
243	0.73	0.17	0.19	0.48		
244	1.5–1.8	0.6	0.30	0.5	0.2	
245	1.5–1.8	0.8	0.28	0.4	0.1	
246	1.5–1.8	1.6	0.38	0.6	0.33	
247	1.9–2.1	0.6	0.37	0.7	0.18	
248	1.9–2.1	1.0	0.21	0.4	0.20	
249	1.9–2.1	1.0	0.36	0.4	0.47	
250	1.9–2.1	1.0	0.42	0.84	0.26	
251	1.9–2.1	2.2	0.44	0.67	0.14	
252	2.1–2.4	0.5	0.30	0.4	0.1–0.25	
253	2.1–2.4	1.45	0.30	0.45	0.24	
254	2.8–3.2	0.45	0.17	0.4	0.15	
255	2.8–3.2	0.34	0.37	0.4	0.12	
256	2.8–3.2	0.9	0.39	0.6	0.23	
257	2.8–3.2	1.4	0.30	0.6	0.14	
258	2.8–3.2	1.5	0.35	0.4	0.25	
259	2.8–3.2	2.0	0.35	0.3	0.3	
260	2.8–3.2	1.7	0.5	0.3	0.3	
261	3.7	0.6	0.17	0.3	0.1	
262	3.3–3.7	0.6–1.0	0.23–0.27	0.4–0.6	0.1–0.2	
263	3.3–3.7	0.7–1.0	0.3 –0.34	0.4–0.7	0.1–0.14	
264	3.3–3.7	1.4–1.6	0.26	0.3	0.1	
265	3.7–4.1	0.9	0.38	0.7	0.15	
266	3.7–4.1	1.4–1.6	0.14	0.4	0.1	
267	3.7–4.1	1.4–1.6	0.31	0.4	0.1	31
268	4.0	2.0	0.27	0.5	0.13	
269	4.7	1.5	0.35	0.6	0.2	
270	5	1	0.2	0.3	0.06	
271	5	20	0.3	0.1	0.08	
272	9.6	23	0.40			
273	16	3	0.5	0.8	0.4	
274	23–25	1.3–1.5	0.9–1.0	1.7–2.0	0.4	
275	23–25	1.3–1.5	0.5	0.24	0.4	
276	30–33	2–3	0.6	0.04	0.25	
277	36	12	0.75	1–2		537

Nickel Copper Steels

Key No.	% composition							Ind. No.
	Ni	Cu	C	Mn	Si	S	P	
279	1.0	0.4	0.45			Tr.		
280	2.26					Tr.		
281	1.7	0.7	0.43			Tr.		
282	1.8	1.7	0.63		0.30	0.06		
283	1.9	1.35	0.45	0.84	1.10	Tr.	Tr.	

Nickel Copper Steels.—(*Continued*)

Key No.	% composition Ni	Cu	C	Mn	Si	S	P	Ind. No.
284	2.0	1.3	0.76					
285	2.1	0.17	0.15	0.91	0.15	Tr.	Tr.	
286	2.1	1.2	0.43					
287	2.3	1.0	0.56	0.48	0.37	0.07		
288	2.4	0.20	0.16	0.77	0.14	Tr.	Tr.	
289	2.45	0.55	0.49	1.03	1.25	Tr.	Tr.	
290	2.45	0.6	0.58	0.90	0.23	Tr.	Tr.	
291	2.45	0.8	0.53		0.21	Tr.		
292	2.5	0.19	0.17	1.07	0.18	Tr.	Tr.	
293	2.5	0.9	0.57	0.33	0.07	0.07		
294	2.5	1.0	0.45			Tr.		
295	2.55	0.6	0.46	0.82	1.30	Tr.	Tr.	
296	2.6	0.36	0.50	0.78	1.25	Tr.	Tr.	
297	2.7	0.6	0.57		0.44	Tr.		
298	2.9	0.5	0.38		0.28	Tr.		
299	2.9	0.6	0.51	1.04	1.35	Tr.	Tr.	
300	3.0	0.7	0.76		0.24		0.1	
301	3.45	0.27	0.43	0.27		Tr.	Tr.	
302	3.6	0.5	0.44	0.50	0.03	Tr.	Tr.	
303	3.9	0.30	0.53	0.79		0.06	Tr.	
304	22.0	9.0	0.22					
305	25	10	0.2					

Iron and Monel Metal (M. M.)

Monel metal contains Ni, 67–68%; Cu, 24–26; Fe, 28–5; Mn, 1.6–2.2.

Key No.	% composition C	M. M.	Key No.	M. M.	Key No.	M. M.
306		2	311	6	316	16
307	0.15	2	312	8	317	18
308	0.10	3	313	10	318	20
309		4	314	12		
310	0.67	4	315	14		

Nickel Vanadium Steels

All these Ni-V steels have traces of P and S except No. 323 which has 0.111% S.

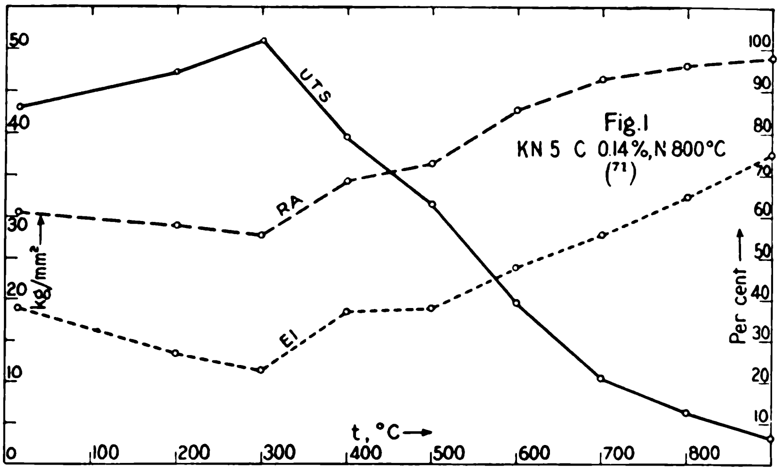
Key No.	% composition Ni	V	C	Mn	Si
319	2.0	0.60	0.15	0.45	0.22
320	2.1	0.30	0.72	0.53	0.41
321	2.2	0.17	0.37	1.4	0.16
322	2.2	7.5	1.25	0.70	0.61
323	2.3	0.35	0.26	0.45	0.54
324	2.3	3.1	0.47	0.54	0.29
325	2.4	0.23	0.45	1.3	0.23
326	2.6	0.68	0.44	0.42	0.22
327	2.6	1.45	0.86	0.65	0.36
328	2.6	6.9	0.38	0.57	0.53
329	2.7	2.9	0.89	0.61	0.40
330	2.9	0.34	0.41	0.25	0.35
331	3.0	0.30	0.38	0.79	1.35
332	3.1	0.21	0.56	1.14	1.09
333	3.15	0.32	0.60	0.79	1.30
334	3.4	0.28	0.24	0.48	0.1
335	3.4	0.60	0.33	0.1	0.12
336	3.6	0.13	0.40	0.1	0.40
337	5.5	0.35	0.19	0.16	0.07
338	6.1	0.60	0.17	0.15	0.07
339	6.2	0.12	0.16	0.13	0.06

Vanadium Steels

Key No.	% composition V	C	Mn	Si	S	P	Ind. No.
340	0.12	0.22	0.72		Tr.	Tr.	
341	0.14	1.06	0.05	0.1	Tr.	Tr.	
342	0.16	0.09	0.21	0.1	Tr.	Tr.	
343	0.16	0.23	0.16	0.1	Tr.	Tr.	
344	0.18	0.33	0.77	0.32	Tr.	Tr.	
345	0.20	1.32	0.33	0.1	Tr.	Tr.	
346	0.21	0.56	0.30	0.1	Tr.	Tr.	
347	0.21	0.98	0.38	0.1	Tr.	Tr.	
348	0.22	0.71	0.31	0.1	Tr.	Tr.	
349	0.23	0.40	0.30	0.1	Tr.	Tr.	
350	0.25	0.82	0.45	0.33	Tr.	Tr.	
351	0.27	0.20	0.48	0.1	Tr.	Tr.	
352	0.3	0.11	0.12	0.11	Tr.	Tr.	
353	0.3	0.45	0.46	0.38			
354	0.3	1.02	0.05	0.1	Tr.	Tr.	
355	0.35	0.74					
356	0.6	0.13	0.36	0.19	Tr.	Tr.	
357	0.6	0.18	0.43	0.15	Tr.	Tr.	
358	0.6	0.72	0.56	0.41	Tr.	Tr.	
359	0.6	1.00	0.05	0.1	Tr.	Tr.	
360	0.7	0.60	0.06	0.05	Tr.	Tr.	
361	0.75	0.14	0.45	0.30	Tr.	Tr.	
362	0.8	0.89	0.33	0.30	Tr.	Tr.	
363	0.8	1.04	0.05	0.1	Tr.	Tr.	
364	0.85	0.05	0.05	0.1	Tr.	Tr.	
365	1.0	0.11	0.38	0.26	Tr.	Tr.	
366	1.1	0.80	0.05	0.1	Tr.	Tr.	
367	1.2	0.67	0.50	0.25	Tr.	Tr.	
368	1.5	0.13	0.30	0.25	Tr.	Tr.	
369	1.6	0.62	0.34	0.29	Tr.	Tr.	
370	2.1	0.20	Tr.	0.22	Tr.	Tr.	
371	2.3	0.63	0.07	0.09	Tr.	Tr.	
372	2.9	0.95	0.22	0.42	Tr.	Tr.	
373	3.0	0.19	0.86	0.29	Tr.	0.08	
374	3.0	0.67	0.70	0.36	Tr.	Tr.	
375	5.0	1.08	0.45	0.46	Tr.	Tr.	
376	5.4	0.38	0.20	0.61	Tr.	0.07	
377	5.8	0.93	0.11	0.21	Tr.	Tr.	
378	7.4	0.13	Tr.	0.41	Tr.	0.11	
379	7.8	0.74	0.31	0.74	Tr	0.12	
380	10.25	0.12	Tr.	0.54	Tr.	Tr.	
381	10.25	0.86	0.56	0.99	Tr.	Tr.	
382	10.25	1.07	0.12	0.32	Tr.	Tr.	
383	13.5	1.10	0.12	0.47	Tr.	Tr.	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
1	As cast..........	29.4	17.7			24.5	33	(7, 18,
	Cast, *A* 950°.....	28.4	14.3			32	48	68, 118,
	Before D_c.......	39.6	26.7	20.5		36.5	69	122)
	D_c 14.8 %.......	55.4	51.0	31.6		17	54	
	Same, *A* 100° 60 m	56.6	50.3	34.7		21	59	
	Same, *A* 200° 60 m	56.0	50.3	33.0		20	57	
	Same, *A* 300° 60 m	55.4	50.3	39.4		21	55	
	Same, *A* 450° 60 m	56.0	43.5	36.2		26	66	
	Same, *A* 550° 60 m	47.9	42.2	34.6		28	66	
	Same, *A* 600° 60 m	43.5	35.2	17.3		30	69	
	Same, *A* 650° 60 m	37.2	19.8	11.0		42	73	
	Normalized......	34.5	22.5	11.3	10.1	37	73	
	1¼ in. diam. 920° Q_w	55.0				30	67	
	1¼ in. diam. 920° Q_o	47.2				35	69	



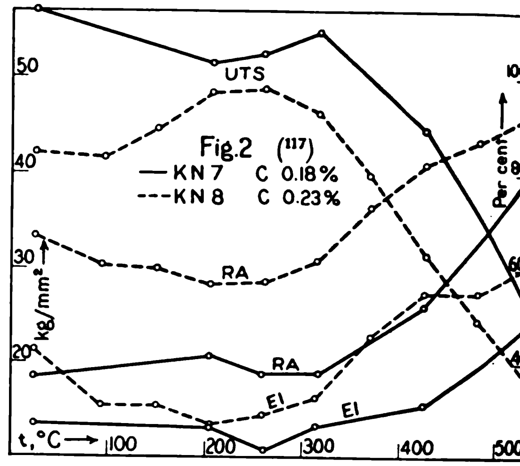


TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
2	R_h 14.3 mm diam.	38.3	27.5	25.3	27.1	29	59.5	(46, 64, 88)
	D_o 13.0 mm diam.	51.0		30.0	32.5	9.5	54	
	D_o 12.0 mm diam.	59.4		35.0	39.5	7	46	
	D_o 10.8 mm diam.	62.2		37.6	43.0	6	32	
	D_o 9.7 mm diam.	65.0		40.0	43.8	4	23	
	R_h 5.2 mm diam.	41.8	28.3	26.0	26.5	31	73	
	D_o 3.97 mm diam.	66.0		39.5	44.5	8.5	45	
	D_o 2.83 mm diam.	83.5		61.5	63.0	6	31	
	D_o 2.37 mm diam.	92.0		73.0	70.0	6	29	
	D_o 2.00 mm diam.	95.0		83.0	78.5	6	30	
	D_o 1.70 mm diam.	100.9		84.5	77.5	6	25	
	D_o 1.37 mm diam.	104.0		87.5	81.5	5	20	
	D_o 1.18 mm diam.	108.1		91.5	85.0	5	25	
	A 800–900°	32.5				28	80	
	750° Q_o	49.0				13	78.5	
	850° Q_o	43.5				16.5	67	
	950° Q_o	48.0				13	61	
3	R_h	35.9	19.4	14.8		38	73	(97, 128, 141)
	A 350°	32.2	19.7	17.7		36_f–44_d	75	
	A 750°	32.9	20.0	16.7		34_f–42_d	74	
	A 850°	33.9	20.8	14.6		34_f–41_d	74	
	A 1000°	33.3	23.9	21.9		36_f–43_d	77	
	750° Q_w	56.4	33.5	13.8		16_f–20_d	54	
	Same, Tp 350°	34.0	20.8	11.8		31_f–39_d	77	
	Same, Tp 550°	32.5	19.7	17.7		35_f–43_d	77	
	Same, Tp 650°	33.4	19.7	15.7		35_f–44_d	78	
	750° Q_o 80°	44.3	26.0	20.6		22_f–28_d	65	
	Same, Tp 350°	32.8	17.3	15.8		33_f–41.5_d	77	
	Same, Tp 550°	32.3	21.7	19.7		35_f–44_d	78	
	850° Q_w	61.8	41.9	17.9		16_f–20_d	65.5	
	Same, Tp 350°	41.5	24.7	11.9		25_f–32_d	80	
	Same, Tp 550°	35.8	23.0	21.7		31_f–40_d	75	
	Same, Tp 650°	33.4	21.3	17.8		33_f–42_d	76	
	850° Q_o 80°	42.7	25.6	17.7		23_f–29_d	66	
	Same, Tp 350°	35.5	19.7	19.7		32_f–41_d	78	
	Same, Tp 550°	35.5	21.7	19.7		35_f–43_d	75	
	1000° Q_w	45.4	34.5	15.8		17_f–25_d	72	
	Same, Tp 350°	41.5	30.6	13.8		24_f–31_d	78	
	Same, Tp 550°	40.7	30.8	21.9		34_f–36_d	79	
	Same, Tp 650°	38.8	29.8	21.9		31_f–41_d	77	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
3	1000° Q_o 80°	39.5	31.8	21.9		31_f–39_d	72	
	Same, Tp 350°	37.9	31.6	28.6		30_f–38_d	69	
	Same, Tp 550°	37.6	33.7	29.7		33_f–43_d	80	
4	N 900°	33.7	22.1	22.1		45	73.5	(65, 128)
	R_h	38.6	23.6	23.1		44	68	
5	R_h	42.6	30.7	25.5		32	66.5	(18, 46, 65, 91, 104, 111, 123)
	R_c 38.5%	43.0	41.5			15	20	
	R_c 64.6%	46.8	*v. also* Fig. 1			13	15	
	R_c 74.5%	57.5				12	3	
	A 670°	43.0	25.2	23.4		28_c–30_b	72	
	A 760°	47.6		24.9		32	68	
	A 866°	38.3	21.8			39.5	67	
	A 1010°	41.5	20.4	17.0			65	
	N 900°	43.7	28.9	22.4		38	64	
	Same, Tp 700° Q_w	44.2	30.1	27.4		38	69	
	Same, Tp 760° Q_w	47.3	26.8	18.9		33	63	
	Same, Tp 820° Q_w	49.4	28.7	17.5		32	62	
	900° Q_w	64.2				28	59	
	Same, Tp 300°	62.1				26	58	
	Same, Tp 400°	60.5	43.9	30.7		27	57	
	Same, Tp 500°	59.2	44.1	34.9		28	58	
	Same, Tp 600°	55.2	40.7	37.0		32	62	
	900° Q_w Tp 760° Q_w 11/16 in. diam.	64.5				28	62	
	900° Q_w Tp 760° Q_w 7/8 in. diam.	61.4				31	64	
	900° Q_w Tp 760° Q_w 1 1/8 in. diam.	58.3				31	65	
	900° Q_w Tp 760° Q_w 1 1/2 in. diam.	55.1				32	65.5	
	900° Q_w Tp 760° Q_w 2 1/8 in. diam.	55.1				32		
	790° Q_o Tp 260°	52.8	32.2			31	62	
	790° Q_o Tp 540°	50.7	32.2			30	65	
	790° Q_o Tp 650°	48.7	30.0			32	70	
	866° Q_o	50.3	39.8			34	75.5	
	Same, Tp 375°	48.2	34.5			38	75.5	
	Same, Tp 460°	48.2	37.3			36	75.5	
	Same, Tp 560°	46.4	34.5			35	75.5	
	Same, Tp 650°	45.0	32.7			38.5	79.5	
	900° Q_o	51.9		Bars 1¼ in. diam.		33.5	67	
	Same, Tp 600°	51.9	39.4			34.5	66	
6	N 920°	48.7	31.5	Bars 1¼ in. diam.		38	64	(18, 89)
	920° Q_w	72.7				22	51	
	Same, Tp 760° Q_w	63.0				32	64	
	920° Q_o	56.6				31	65	
	A 925°	35.3	17.9			38	63	
	900° Q_o 760° Q_o, 260° C_a	40.3	23.2			36	69	
7	Cast	31.6	18.6			19.5	21	(7, 26, 41, 61, 88, 104, 110, 111, 120,
	R_h	43.3	27.0	22.3	27.8	39	68	
	R_h to 0.48 in. diam.	46.7	44.5	42.1	42.2	22	68	
	R_h to 0.44 in. diam.	50.8	None	48.9	49.5	14	63	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
7	A { 350°	42.6	25.7	24.6		30_f-37_d	61.5	141)
	500–540°	40.9	22.6			48_a-35_c	63	
	680°	39.7	21.1			47_a-33_c	66	
	750°	48.5	27.4	27.5		$31_f-38.5_d$	62	
	800–820°	39.8	22.2			46_a-33_c	64.5	
	850°	41.5	26.0	21.8		30_f-37_d	60.5	
	Cast *A* 950°	30.7	14.7			31_a	47	
	A 1000°	44.6	33.1	26.7		31_f-38_d	64	
	750° Q_w	56.3	33.0	12.5		16_f-19_d	52	
	Same, Tp { 350°	43.2	25.8	16.8		26.5_f-33_d	62	
	550°	41.9	25.7	26.6		29_f-36_d	63	
	650°	42.8	25.6	21.1		30.5_f-37_d	60.5	
	750° Q_o 80°	49.3	29.5	24.6		21.5_f-26_d	58	
	Same, Tp { 350°	42.0	24.5	21.1		28.5_f-35_d	63	
	550°	41.0	25.8	21.1		$30_f-37.5_d$	62	
	790° Q_o Tp { 260°	65.2		34.0		26	57	
	540°	62.0		42.2		28	60.5	
	650°	59.4		37.6		34	65	
	1000° Q_w	61.8	44.5	16.3		$11_f-17.5_d$	65.5	
	Same, Tp { 350°	57.4	39.1	19.8		$14_f-20.5_d$	66	
	550°	58.1	42.2	25.9		16.5_f-21_d	66.5	
	650°	52.4	39.6	36.6		20.5_f-32_d	69	
	1000° Q_o 80°	51.3	37.8	25.3		25_f-33_d	65	
	Same, Tp { 350°	53.8	38.6	30.7		$21_f-27.5_d$	67.5	
	550°	51.9	37.1	25.7		21.5_f-29_d	67.5	
	D_e	61.0	None		36.6	14_a	49	
	D_e A 705°	39.8	20.7	18.8	18.2	41_a	65.5	
	D_e A 845°	40.5	21.1	19.7	18.0	41_a	63	
	v. also Fig. 2							
8	Cast (*v. also* Fig. 2)	38.9	16.2	9.0		12	13.5	(41,67, 141)
	Cast, A { Large	44.4	21.6	17.1		31	49	
	Small	49.4	25.2	21.5		35.5	53	
	R_h	52.0	27.6	20.7		25_f-30_d	51	
	A { 350°	49.6	27.5	25.6		26_f-33_d	58	
	750°	47.7	26.3	23.7		28_f-35_d	59	
	850°	49.6	27.7	20.8		27_f-33_d	51	
	1000°	53.3	34.2	30.1		26_f-32_d	51	
	750° Q_w	58.8	36.2	15.7		20_f-22_d	53	
	Same, Tp { 350°	49.2	28.2	15.8		25_f-31_d	58	
	550°	48.5	27.0	23.6		27.5_f-35_d	59	
	650°	50.8	27.6	17.7		$27_f-33.5_d$	56	
	750 ° Q_o 80°	51.2	29.8	23.6		21.5_f-27_d	58	
	Same, Tp { 350°	48.2	27.9	25.6		27_f-33_d	59	
	550°	50.0	26.8	21.7		27_f-34_d	57	
	850° Q_w	73.4	41.6	15.8		$6_f-8.5_d$	14	
	Same, Tp { 350°	119.8	101.0	29.7		4_f-6_d	27	
	550°	78.9	61.3	49.4		10_f-15_d	50	
	650°	65.2	45.4	35.6		15_f-20_d	58	
	850° Q_o 80°	66.0	43.3	15.7		14_f-20_d	51	
	Same, Tp { 350°	68.0	42.4	21.7		16_f-21_d	57	
	550°	64.0	39.3	31.4		17_f-23_d	55	
	1000° Q_w	76.0	48.4	16.8		11_f-15_d	49	
	Same, Tp { 350°	116.2	83.4	33.8		4_f-7_d	36	
	550°	73.4	50.6	39.7		14_f-18_d	62	
	650°	67.4	49.5	41.6		15_f-20_d	65	
	1000° Q_o 80°	68.6	46.7	37.7		16.5_f-22_d	56.5	
	Same, Tp { 350°	71.1	47.4	37.5		15_f-20_d	52	
	550°	66.9	45.4	41.4		14_f-19_d	55	
9	R (*v.* Fig. 3)	43.1	20.6			$43_a-38_b-32_c$	57	(26)
	760°/30 C_f	41.9	21.8			$42_a-37_b-32_c$	58	
	500°/30 C_a	42.6	21.3			$44_a-38_b-33_c$	57	
	700°/30 C_a	40.3	19.6			$45_a-41_b-35_c$	59	
	As received	45.7		28.2		29	63	
	800°/2 Q	61.2		45.3		4.5		
	800°/20 Q	72		53.6		2.5		
	800°/60 Q	71.2		46		2		
	950°/2 Q	101.3		68.8		2	5	
	950°/20 Q	120.3		90		3.5	10	
	950°/60 Q	128.1		95.7		3?	7?	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
10	As received	46.5		28.1		24	53	(120)
	800°/2 Q	58		34.3		16	57	
	800°/20 Q	62		39		16.5	57	
	800°/60 Q	58.6		36.2		18.5	60	
11	R 5 SWG	48.8				39	58	(97)
	Same, A	37.8				37	73	
	25 SWG wire	72.8				4		
12	R (*v. also* Fig. 4)	51.9	23.0			15_g	30	(113, 114)
	A { 750°	51.6				26_g	51	
	800°	53.2				22_g	52	
	850°	50.5	28.2			21_g	50	
	950°	53.2				20_g	46	
	1000°	53.9				19.5_g	44	
	N 900°	55.9	38.6		←Bars 1¼ in. diam.→	32_a	59	
	900° Q_w					11_a	30	
	Same, Tp { 300°					12_a	32	
	400°		59.8			15_a	44	
	500°		56.6			23_a	58	
	600°	67.7	48.8			28_a	64	
	900° Q_o	69.3				25_a	55	
	Same, Tp { 300°	69.3				26_a	57	
	400°	69.3				26_a	59	
	500°	67.7	48.8			27_a	60	
	600°	63.0	44.1			29_a	64	
13	N 870°	53.5	34.6		←Bars 1¼ in. diam.→	34	58	(46, 60, 67, 75)
	870° Q_w	69.2				24	56	
	Same, Tp { 300°	67.7				24	57	
	400°	69.2				25	58	
	500°	66.1	50.4			27	60	
	600°	63.0	45.6			29	64	
	700°	58.2	40.8			33	68	
	870° Q_o	64.5				28	60	
	Same, Tp { 300°	64.5				28	60	
	400°	64.5				28	61	

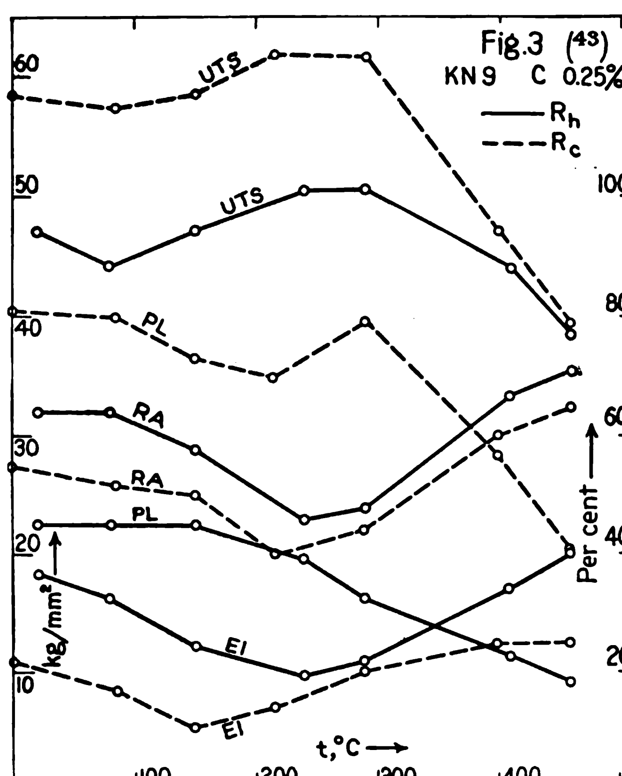


TABLE 2, PART I.— CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
13	Same, Tp Cont'd. 500°	63.0	45.6			29	61	
	600°	61.4	42.5			31	63	
	700°	56.6	39.4			34	68	
	R_h 15 mm diam.	48.7	32.8	25.7	26.2	30	59.5	
	D_c 14.3 mm diam.	62.8		26.5	26.2	13	49	
	D_c 13.8 mm diam.	68.0		29.5	31.4	9	43	
	D_c 13.2 mm diam.	73.0		33.7	34.0	4.5	39	
	D_c 12.7 mm diam.	74.6		39.0	38.8	4.5	35	
	D_c 11.2 mm diam.	86.4		48.9	46.0	3	25	
	D_c 8.2 mm diam.	96.6		57.0	55.4	3	23	
	F, longitudinal	44.6	21.5	18.6		33.5	53	
	F, transverse	40.1	17.0	12.6		22.5	33.5	
	v. also Fig. 30							
14	R_h	55.1	28.0	18.7		24_f–30_d	53	(49, 91, 111, 141, 146)
	A 350°	55.0	29.5	25.6		26_f–31.5_d	55	
	A 750°	52.6	28.4	24.6		25_f–31_d	55	
	A 850°	53.1	26.5	21.8		26_f–32_d	54	
	A 900°	48.7	21.3	15.7		33_a	51	
	A 1000°	57.3	34.2	30.1		26_f–32_d	57.5	
	750° Q_w	61.8	40.3	15.7		19_f–23_d	52	
	Same, Tp 350°	54.7	27.2	17.7		25_f–30_d	55	
	Same, Tp 550°	53.7	27.5	21.6		24_f–30.5_d	55	
	Same, Tp 650°	54.1	29.6	21.7		25_f–31_d	52	
	750° Q_o 80°	54.8	28.1	22.3		34_a	55	
	Same, Tp 350°	53.7	28.2	21.7		26_f–32_d	55	
	Same, Tp 550°	53.3	26.6	25.6		24_f–31_d	55	
	Same, Tp 650° C_f 1°/m	47.7	22.2	17.3		38_a	63	
	Same, Tp 650° Q_w	49.6	24.5	17.3		35_a	62	
	850° Q_w	95.2				8_a	17	
	850° Q_o 80°	74.5	50.2	31.5		23.5_a	62	
	Same, Tp 350°	72.8	49.5	29.5		22.5_a	62	
	Same, Tp 460°	69.6	47.1			23_a	62	
	Same, Tp 550°	68.9	47.0	43.3		26.5_a	65	
	Same, Tp 650°	59.0	43.2			30_a	71	
	870° Q_w	141.0	128.3	87.3		3_a	2.5	
	Same, Tp 400°	103.9	90.0	74.1		7.5_a	27	
	Same, Tp 500°	99.3	86.6	67.0		17_a	18	
	Same, Tp 600°	79.0	57.1	54.3		13_a	26	
	900° Q_o 650°/120 Q_w	55.4	32.4	25.2		33_a	64	
	Same, but C_f 1°/m	52.4	28.9	25.2		33_a	65	
	1020° Q_o, Tp 650°/120 Q_w	52.1	28.9	22.1		35_a	64	
	1250° Q_o, Tp 650°/120 Q_w	55.2	33.7	22.1		30_a	61	
	Same, but C_f 1°/m	49.7	28.7	18.9		38_a	63	
15	As cast	53.6	23.6	14.0		26	34	(65, 88, 95, 146)
	A 925° C_f	56.1	29.0	26.1		27	39.5	
	N 925° C_a	59.7	32.2	28.5		28	46	
	N 850°	55.8	32.9	31.8		30.5	55	
	A 816°	40.5	21.7			15	27	
	A 893° 870° Q_w, Tp 482°	61.7	43.5			4	8	
	A 871° 870° Q_w, Tp 482°	65.2	43.1			12	15	
	Wire 5 mm diam.	62.8				6	12	
	A 800–900°	47.9				18	60	
	750° Q_o	74.4				7	48	
	850° Q_w	120.7				0	0	
	950° Q_w	145.3				0	0	
	Same, Tp 100°	168.6				3	12	
	Same, Tp 200°	155.6				6	27.5	
	Same, Tp 300°	134.4				8.5	36.5	
	Same, Tp 400°	111.2				10	48	

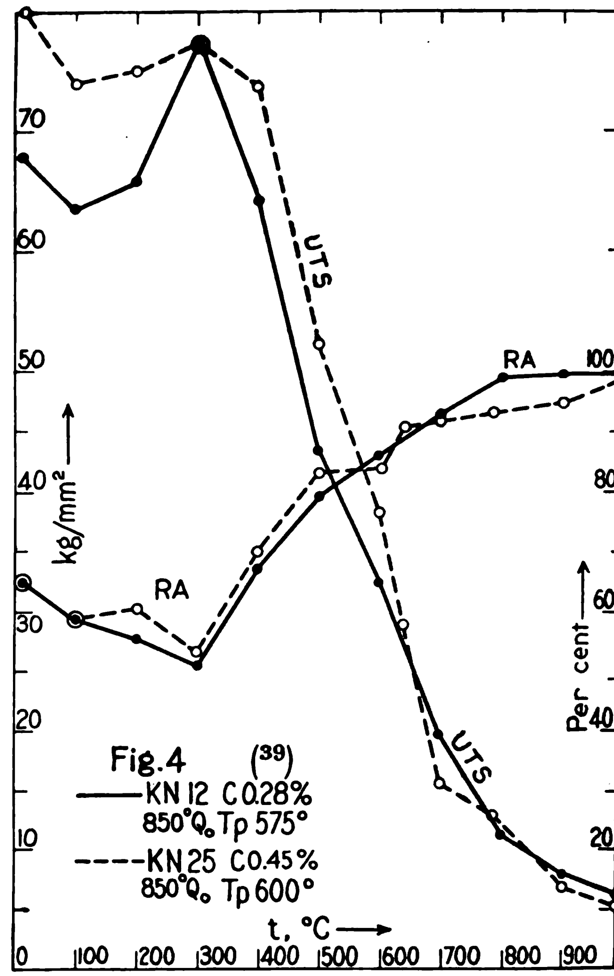


Fig.4 (39)
——KN 12 C 0.28% 850° Q_o Tp 575°
----KN 25 C 0.45% 850° Q_o Tp 600°

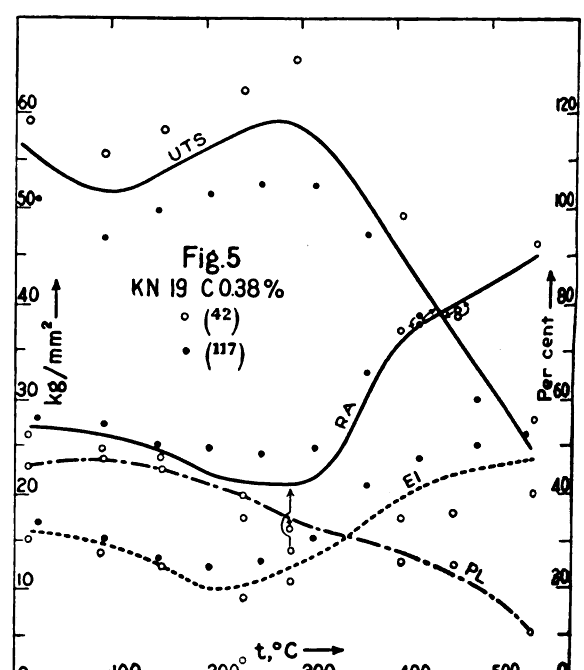


Fig.5
KN 19 C 0.38%
○ (42)
• (117)

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
16	A 675°/30	40.1	21.0	19.7			62	(123)
	A 1150°/30	41.7	15.0	11.2			54	
	A 1115°/120	40.6	13.8	11.8			55	
	Rolled	46.2	27.4	26.3			61	
17	A 900°	50.3	25.0			26	39	(67, 89)
	850° Q_w 600° C_t	57.3	33.4			26	61	
	F { longitudinal	57.8	26.7	22.1		27	42	
	F { transverse	54.1	25.7	20.2		18	31	
	F { radial	55.3	27.0	19.6		23.5	36	
18	As cast	35.4	24.2			5.5	6	(7, 81)
	A 950°	34.0	15.2			16	21	
	900°, Q_o, Tp { 600°/2h C_a	60.5	38.7	34.6		29	64	
	900°, Q_o, Tp { 650°/2h Q_w	55.1	37.4	28.4		32	68	
	900°, Q_o, Tp { 650°/2h C_a	54.1	37.2	29.9		32	69	
19	Rolled	53.2	25.5	21.1	*v. also* Fig. 5.	31	49	(49, 68, 72, 94, 110)
	N 850°	52.7	29.7	27.4		30	53	
	A 850°	50.6	28.1	24.4		32	50	
	900°/60 C_a, 760°/60 Q_o	61.4	30.8	23.6		29	50	
	Same, 650° /120 { Q_w	54.3	28.7	20.4		35	58	
	Same, 650° /120 { C_t 1°/m	52.1	24.4	18.7		34	58	
	900°, 60 Q_o, 60C_t { Q_w	62.4	36.8	26.7		27	56	
	900°, 60 Q_o, 60C_t { C_t 1°/m	59.6	32.0	25.2		30	56	
	900°/60C_t	54.3	23.9	12.6		29	43	
	900° /30, C_aW { 600° } 5h, C_a	54.0	32.3	31.1		32	57	
	900° /30, C_aW { 680° } 5h, C_a	49.6	28.5	26.6		39	63	
	900° /30, C_aW { 750° } 5h, C_a	48.0	27.8	27.1		40	65	
20	R_h	54.8	32.2	31.6		33.5	58	(128)
21	As cast	34.3	24.0			7.5	10	(7)
	A 950°	37.4	17.6			19	23	
22	R_h	65.1	30.5	25.6		19_t–23_d	43	(141)
	A { 350°	69.0	33.4	29.5		20_t–24_d	39	
	A { 750°	64.5	32.5	26.6		21_t–26_d	48	
	A { 850°	64.4	35.6	33.7		24_t–28_d	46	
	A { 1000°	65.8	36.1	34.1		22_t–27_d	48	
	750° Q_w	55.5	35.4	19.7		17.5_t–21_d	41	
	Same, Tp { 350°	65.9	32.5	19.7		20_t–24_d	44	
	Same, Tp { 550°	64.1	31.8	25.6		20_t–25.5_d	44	
	Same, Tp { 650°	67.4	32.5	28.6		21.5_t–27_d	53	
	750° Q_o 80°	66.6	33.5	25.6		18_t–22_d	44	
	Same, Tp { 350°	63.7	30.2	25.6		20_t–25_d	44	
	Same, Tp { 550°	62.2	30.4	25.6		22_t–26.5_d	57	
	850° Q_w	87.9	57.4	13.8		0.3_t–0.6_d	2.5	
	Same, Tp { 350°	169.6		33.3		3_t–3.5_d	17	
	Same, Tp { 550°	109.6	91.0	65.2		10_t–14_d	55	
	Same, Tp { 650°	82.3	67.2	49.4		13_t–19_d	59	
	850° Q_o 80°	96.5	68.9	46.3		12_t–15_d	39	
	Same, Tp { 350°	97.5	65.0	45.3		12_t–14_d	46	
	Same, Tp { 550°	88.5	61.0	51.1		13_t–17_d	49	
23	Wire 5 mm diam.	63.1				4.5	12	(88)
	A 800–900°	57.3				19	60	
	750° Q_o	107.6				5	37	
	850° Q_o	149.3				0	0	
	950° Q_o	139.0				0	0	
	850° } Q_w	80.0				0	0	
	950° } Q_w	56.5				0	0	
24	N 820°	65.4	36.4	34.1		25	47	(67, 72)
	Tangential	61.5	31.0	20.2		22	29	
	Longitudinal	61.7	29.5			25	38	
	Radial	64.6	33.2	18.5		12	21	
25	N 870°	69.4	42.5			27	54.5	(18)
	Bars 1¼ in. diam. (*v. also* Figs. 4, 31, 50 and 51)							
27	As received	63.5	37.2			21.5	35	(72, 110, 111)
	N	68.2	35.9	32.3		23	42	
	A 816–819°	57.9	33.2			28.5	46	
	816–819° Q_w	141.1				0.5	0	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
27	816–819° Q_o	90.1	61.6			19	52	
	Same, Tp { 375°	91.0	61.8			20	52	
	Same, Tp { 460°	87.9	60.0			19	52	
	Same, Tp { 560°	79.6	55.6			24	57	
	Same, Tp { 650°	71.9	52.3			26	61	
	775° Q_w 650° C_t	68.1	48.3	47.6		23.5	58	
28	N	71.2				18.5	31.5	(97,144)
	A 5 SWG rod	68.4				17	55	
	15 SWG wire	141.7				2	20	
	17 SWG wire	157.5				1.5	5	
29	As cast	28.9	28.9			3	3	(7)
	A 950°	42.0	16.9			20.5	16	
30	A 840°	49.0		29.4		5	6	(146)
32	A 840°	55.2		25.4		6	4.5	(46, 66, 110, 146)
	N 875°	69.4	33.7	31.4		25	40	
	790° Q_w Tp 650° C_a		59.3	56.4		22	57	
	R_h 5.37 mm diam.	65.5	36.9	26.0	25.0	23	38	
	D_c { 4.37 mm diam.	98.5		45.0	52.5	7	19	
	D_c { 3.60 mm diam.	111.3		48.0	54.0	6	15	
	D_c { 3.00 mm diam.	119.5		57.0	61.5	6.5	14	
	D_c { 2.48 mm diam.	133.4		68.5	74.5	6	14	
	D_c { 1.98 mm diam.	142.2		68.0	92.0	6	13	
33	(*v.* Fig. 32)							
34	As cast	33.3	26.4			3	3	(7)
	A 950°	39.8	18.0			13	14	
35	As received	83.6	46.4	[Test piece 160 mm long]		13.5	34	(45)
	850° Q_o Tp 710°	77.3	56.8			17	47	
37	As cast	29.6	19.6			1.5	2	(7)
	A 950°	25.9	15.5			2	2	
39	As received	74.5	39.9			19	27	(67, 111)
	N 810°	76.5	45.8	42.4		22	38	
	A 809°	66.5	35.0			25	40	
	809° Q_w	150.5				0	0	
	809 Q_o	106.4	73.5			16.5	40	
	Same, Tp { 375°	107.4	74.5			16	43	
	Same, Tp { 460°	101.8	68.2			16	46	
	Same, Tp { 560°	93.1	65.4			20.5	52	
	Same, Tp { 650°	79.4	55.6			24	62	
40	FW; C_a	84.0				19	34.5	(112, 142)
	A { 0°	57.96				3	3	
	A { 700°	54.5				6	8	
	A { 730°	54.3				5	4	
	A { 760°	56.6				6	8	
	A { 775°	58.8				5	5	
	A { 790°	59.0				8	13	
	A { 820°	61.5				7	7	
	A { 850°	62.1				7	7	
	A { 900°	62.7				7	7	
	A { 1000°	63.4				5	7	
	Test piece 200 mm × 20 mm diam.							
41	R_h 15 mm diam.	80.9	49.4	27.4	26.8	17	26	(46)
	D_c { 14.3 mm diam.	97.0		31.0	30.0	3	15	
	D_c { 13.9 mm diam.	101.4		31.7	31.9	3	7	
	D_c { 13.2 mm diam.	105.8		39.3	39.0	2	8	
	D_c { 12.7 mm diam.	111.5		39.0	39.8	2.5	8	
	D_c { 11.2 mm diam.	122.0		50.7	49.6	2.5	6	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
42	R_h	77.1	34.4	25.6		13_f–15.5_d	22	(141)
	Same, A 350°	80.4	36.4	31.5		13_f–16_d	20	
	Same, A 750°	73.6	33.6	23.7		16_f–19_d	27	
	Same, A 850°	77.9	41.7	38.6		16_f–19_d	31	
	Same, A 1000°	77.1	44.1	38.1		12_f–20_d	30	
	750° Q_w	79.6	37.4	17.7		14_f–16_d	26	
	Same, Tp 350°	72.9	35.4	15.8		15_f–17_d	22	
	Same, Tp 550°	74.7	34.4	29.5		16_f–19_d	27	
	Same, Tp 650°	73.2	34.4	31.5		15_f–18_d	26	
	750° Q_o 80°	74.2	34.4	28.6		17_f–21_d	30	
	Same, Tp 350°	86.0	33.5	29.5		17_f–20.5_d	30	
	Same, Tp 550°	71.6	33.4	28.5		17_f–21_d	29	
	850°, Q_w Tp 350°	155.3		55.8		0_f–0_d	0	
	850°, Q_w Tp 550°	111.1	94.5	78.8		9_f–13_d	30	
	850°, Q_w Tp 650°	85.8	72.9	63.1		11_f–15.5_d	33	
	850° Q_o 80°	115.2	78.8	55.1		8.5_f–10_d	35	
	Same, Tp 350°	118.1	82.7	55.1		8_f–11_d	38	
	Same, Tp 550°	106.3	70.9	59.1		11_f–16_d	44	
45	(v. Fig. 24)							
47	As received	89.6	46.2			15	21	(111)
	A 800°	78.4	32.6			17	24	
	800° Q_o	129.1	70.0			2	0	
	Same, Tp 375°	125.3	85.0			4		
	Same, Tp 460°	123.9	80.8			10	34	
	Same, Tp 560°	103.9	74.2			17	43	
	Same, Tp 650°	87.5	63.7			20	57	
48	Sandberg Trt.*	120.2	92.8			14	16	(5)
	C_aW_1 850°	91.7				13	18	
	C_a	90.1				11	10	
49	5 SWG rod R	79.5				17	37	(7, 97)
	5 SWG rod A	50.5				26	60	
	25 SWG wire	82.0				5		
	As cast	31.7	29.2			2	2	
	A 950°	47.7	21.9			6	5	
50	Sandberg Trt.*	127.9	81.6			13	20	(5)
	C_aW_1 840°	92.8				15	23	
	C_a	97.8				Broke off close		
51	R_h 5.3 mm diam	81.2	52.3	24.5	26.0	19	36	(46, 141)
	D_o 4.58 mm diam	101.4		38.5	36.0	8	24	
	D_o 4.22 mm diam	109.0		38.5	43.0	7	20	
	D_o 3.84 mm diam	121.0		45.5	44.0	6	20	
	D_o 3.43 mm diam	126.2		48.5	46.5	6	18	
	D_o 3.03 mm diam	128.0		48.0	46.0	6	16	
	A 350°	94.8	45.3	38.4		11_f–11_d	15	
	A 750°	87.2	40.5	34.5		12_f–15_d	21	
	A 850°	91.9	45.4	39.5		13_f–15_d	25	
	A 1000°	94.3	48.2	44.2		12_f–15_d	21	
	750° Q_w	91.6	43.3	17.8		12_f–13_d	17	
	Same, Tp 350°	90.2	45.3	27.6		11_f–13_d	18	
	Same, Tp 550°	87.9	39.3	33.4		13_f–15_d	30	
	Same, Tp 650°	89.1	40.4	31.5		13_f–15_d	21	
	750° Q_o 80°	89.6	41.4	34.5		12_f–14_d	19	
	Same, Tp 350°	88.5	40.3	31.5		12_f–15_d	21	
	Same, Tp 550°	89.3	39.3	34.4		13_f–15_d	19	
	850° Q_w Tp 550°	125.3	106.6	98.7		7_f–11_d	27	
	850° Q_w Tp 650°	95.6	81.8	69.0		11_f–14_d	53	
	850° Q_o 80°	140.8	82.4	74.8		7_f–9_d	30	
	Same, Tp 350°	140.0	94.6	63.1		9_f–12_d	50	
	Same, Tp 550°	126.0	86.6	75.5		8_f–9_d	29	
52	N 825°	95.6	51.2	32.9		13_a	23	(46)
53	As received	68.4		36.8		10		(120)
	800°/2 Q	70.2		36.1		13	25	
	800°/20 Q	65.3		35.1		4	3	
	800°/60 Q	93.2		93.2				

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
54	A 845°	70.3	25.2			13_a	13	(89, 111, 122)
	800° Q_o 450° C_f	106.7	65.7			12_a	26	
	Before D_o	97.7	48.8	39.4		15_a	22	
	D_o 8.1 %	111.8	87.9	34.6		6_a	18	
	A 100° 1 h	113.1	96.0	37.8		5_a	17	
	A 200° 1 h	118.1	105.5	75.6		5_a	14	
	A 300° 1 h	118.1	102.3	77.3		5_a	14	
	A 450° 1 h	110.2	81.8	69.2		9_a	17	
	A 650° 1 h	91.4	56.7	50.3		14_a	29	
	A 700° 1 h	81.8	39.4	28.3		24_a	38	
	795° Q_w	65.1				0	0	
	795° Q_o	129.1	96.9			4	6	
	Same, Tp 375°	138.9				12	34	
	Same, Tp 460°	136.1	93.8			14	37	
	Same, Tp 560°	112.7				19	40	
	Same, Tp 650°	90.3	68.2			19	46	
56	A 5 SWG rod	80.0				17_a	46	(97)
	15 SWG wire	164.0				1.5_a	3	
58	N 850°	93.5	51.0	36.4		11_a	16	(87)
60	790° C_f	59.1	23.5	19.7	17.9	25_a	37	(116, 141)
	790° Q_o 650° C_a	80.3	47.5	42.4	42.6	23_a	40	
	790° Q_o 450° C_a	128.5		68.2	71.8	10_a	29	
	R_h	98.1	46.1	34.5		7_f–7.5_d	8.5	
	A 350°	102.3	47.2	43.3		8.5_f–9_d	10.5	
	A 750°	94.2	43.4	31.5		10.5_f–13_d	15.5	
	A 850°	91.8	45.5	40.5		13.5_f–15.5_d	23.5	
	A 1000°	107.6	56.1	48.1		8.5_f–8.5_d	11	
	750° Q_w	99.4	49.2	31.5		6_f–10_d	12.5	
	Same, Tp 350°	96.8	45.3	23.7		10_f–11.5_d	14.5	
	Same, Tp 550°	100.6	43.3	33.5		10.5_f–11.5_d	12.5	
	Same, Tp 650°	96.6	51.3	33.5		10.5_f–11.5_d	13.5	
	750° Q_o 80°	98.3	45.3	35.4		10_f–11.5_d	16	
	Same, Tp 350°	92.8	43.7	38.4		11_f–12_d	15	
	Same, Tp 550°	92.8	43.3	39.3		10_f–12_d	16	
	850° Q_w	96.1		35.5		0_f–0_d	0	
	Same, Tp 550°	132.4	96.3	62.9		6_f–9_d	15	
	Same, Tp 650°	100.2	84.5	76.6		10_f–13_d	35	
	850° Q_o	146.7	106.2	72.8		6_f–8_d	25	
	Same, Tp 350°	147.8	100.5	71.0		6_f–8_d	28	
	Same, Tp 550°	135.7	90.5	51.7		6_f–8_d	13	
61	D_o 15.0 mm diam	103.0	54.5	27.2	27.5	7	8	(46)
	D_o 14.3 mm diam	116.0		32.3	32.7	1	3	
	D_o 13.9 mm diam	121.0		37.9	36.9	1	3	
	D_o 13.2 mm diam	126.5		38.0	37.5	1	3	
	D_o 12.7 mm diam	131.0		44.2	43.3	0	2.8	
62	815° Q_o Tp 455°	140.2	79.8			7	8	(30)
	825° Q_o Tp 455°	150.0	79.8			6	13	
	815° Q_o, Tp 585°	110.1	72.1			7	9	
	815° Q_o, Tp 655°	89.9	49.2			12	22	
	815° Q_w Tp 700°	74.5	56.3			14	34	
63	As cast	51.0	35.0			2	2	[illegible]
	A 950°	45.7	29.2			4	[illegible]	
	875° Q_w Tp 450°	142.0	106.1			9	[illegible]	
	875° Q_o Tp 450°	140.6	118.7			8	[illegible]	
64	N 815°	91.4		38.7		14_a	[illegible]	
	780°/30 Q_w Tp 538° 15 min	80.8		70.3		14.5_a	[illegible]	
	843°/30 Q_w Tp 538° 15 min	98.4		61.2		7_a	[illegible]	
	788°/30 Q_o Tp 538° 15 min	110.0		64.1		11_a	[illegible]	
	788° Q_{salt}†	100.5		55.9		[illegible]	[illegible]	
	788° Q_{Pb}‡	92.1		49.4		[illegible]	[illegible]	
	843° Q_{Pb}§	96.0		50.1		11_a	[illegible]	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
64	843°/30 Q_o Tp 538°	135.0		84.4		11_a	29.5	
	843°/300 Q_o Tp 538°	139.0		86.5		9.5_a	23	
	760°/30 Q_o Tp 538°	123.3		79.4		11_a	40	
	760°/300 Q_o Tp 538°	135.2		93.8		8_a	22.4	
	Following specimens wet ground after treatment							
	780°/30 Q_w Tp 538° 15 min	113.1	(*v. also* Fig. 33)	96.7		12_a	31	
	843°/30 Q_w Tp 538° 15 min	116.8		89.7		10_a	31	
	788°/30 Q_o Tp 538° 15 min	125.5		78.6		13_a	39	
	788° Q_{salt}†......	100.9		60.1		14.5_a	35.5	
	788° Q_{Pb}‡.......	105.5		58.0		15_a	37	
	760° 30 Q_o, Tp 538°, 20 m C_o	110.0		71.0		13.5_a	44	
	788° 30 Q_o, Tp 538°, 20 m C_o	125.5		78.6		13_a	39	
	816° 30 Q_o, Tp 538°, 20 m C_o	131.9		83.6		11_a	30	
	871° 30 Q_o, Tp 538°, 20 m C_o	124.9		82.9		12_a	30	
	840° Q_o Tp 704°/1 h	82.7		56.3		19	48	
	840° Q_o Tp 704°/5 h	63.3		44.4		33	61	
65	5 SWG rod R..	98.8				10	15	(97)
	5 SWG rod A..	62.6				25	52	
	25 SWG wire....	94.5				5		
68	N..............	81.9	42.5	41.0	41.4	8_a	11.5	(110, 141)
	790° Q_o Tp 460°.	126.5	91.4	84.4	84.3	9_a	15	
	R_h..............	88.6	51.2	35.4		2.5_f–2.5_d	4	
	A 350°.........	101.3	53.1	49.2		3.5_f–4.5_d	4	
	A 750°.........	95.6	49.3	46.3		10_f–10.5_d	12.5	
	A 850°.........	87.9	47.2	40.3		15_f–18_d	25	
	A 1000°........	103.8	57.7	55.8		4_f–4_d	4	
	750° Q_w.........	100.4	53.2	25.6		5_f–5_d	6	
	Same, Tp 350°.....	97.7	47.3	29.6		6_f–6.5_d	5	
	Same, Tp 550°.....	98.5	49.2	41.4		5.5_f–5.5_d	6	
	Same, Tp 650°.....	98.4	51.2	43.3		8_f–10_d	8.5	
	750° Q_o 80°......	98.3	51.1	45.2		9_f–9.5_d	11	
	Same, Tp 350°.....	98.5	49.2	45.3		8_f–9_d	7.5	
	Same, Tp 550°.....	98.1	49.2	43.3		8.5_f–10_d	9.5	
	850° Q_w Tp 350°...	125.4		77.8		0_f–0_d	0	
	850° Q_w Tp 550°...	141.3	113.8	64.8		6_f–6.5_d	11	
	850° Q_w Tp 650°...	103.6	82.1	77.3		8_f–11_d	30	
	850° Q_o 80°......	147.1	108.4	78.9		8_f–9_d	15	
	Same, Tp 350°.....	143.8	92.6	70.1		6_f–8_d	20	
	Same, Tp 550°.....	131.0	85.2	54.3		4_f–5_d	11.5	
69	R 5 SWG rod....	84.7				14	15	(97, 111)
	25 SWG wire....	94.5				6		
	As received......	106.0	54.2			3		
	A 790°..........	70.0	34.3			24.5	40	
	790° Q_w.........	116.2				0	2	
	790° Q_o.........	141.0	85.7			9	17	
	Same, Tp 375°.....	142.1	91.7			8	13	
	Same, Tp 460°.....	139.5	85.7			8.5	13	
	Same, Tp 560°.....	120.0	74.2			11.5	20.5	
	Same, Tp 650°.....	97.6	61.6			15.5	34	
72	Normalized......	78.7	37.0	34.6		4.5_h	4	(37)
	F 900–800° A 750°/300, A_s 670°/180	62.2	30.7	28.3		20.5_h	25	
	F 750–700° A A_s 670°/240	58.3	26.8	19.7		26.0_h	30	
73	As cast..........	34.8	34.8			0	0	(7)
	A 950°..........	47.2	26.1			2.5	3.5	
76	As received......	97.3	52.1			2	2	(111)
	A 790°..........	68.6	36.0			15.5	20.5	
	790° Q_w.........	98.3				1	0	
	790° Q_o.........	131.9	68.2			2.5	5.5	
	Same, Tp 375°.....	110.9	87.5			2.5	5.5	
	Same, Tp 460°.....	93.8	86.4			3.5		
	Same, Tp 560°.....	112.7	71.0			4	5.5	
	Same, Tp 650°.....	92.0	59.8			11	17	

TABLE 2, PART I.—CARBON STEELS (TENSILE PROPERTIES).—(*Continued*)

Key No.	Treatment	*UTS*	*YP*	*PL*	*EL*	*El*	*RA*	Lit.
78	5 SWG rod R...	88.8				4	15	(97)
	5 SWG rod A..	65.9				11	15	
	25 SWG wire....	94.5	*v. also* Fig. 6			7.5		
81	As cast..........	32.0	32.0			0	0	(7)
	A 950°..........	22.2	18.4			0	0	
82	As cast..........	20.7	20.7			0	0	(7)
	A 950°..........	20.2	20.2			0	0	

* Sandberg treatment consists of cooling the tire at a certain rate through the critical range of temperature, by subjecting it as it slowly revolves, to the blast of a large quantity of moist air.

† 788°/30 Q_{salt} 538°/15 C_o.

‡ 788°/30 Q_{Pb} 538°/15 C_o.

§ 843°/60 Q_{Pb} 538°/30 C_o.

TABLE 2, PART II.—COMPRESSION TESTS ON CARBON STEELS*
v. also Figs. 14, 15, 16, and 27

Specimen loaded to failure

Key No.	Treatment	*UCS*	YP_C	PL_C	EL_C	Lit.
1	Before D_c.......		25	20.5		(110, 122)
	D_c 14.8 %.......		48	30		
	N..............	22	14.5	13.5	13.5	
3	R_h..............	37	19.5	19		(128)
4	R_h..............	40.5	25	24.5		(128)
19	N 815°..........	41.5	26.5	25.5	26	(110)
20	R_h..............	57	32.5	29		(128)
27	775° Q_w 650° C_f..	54	42	39	40.5	(110)
32	N 845°..........	55.5	36	33.5	34	(110)
	790° Q_w 650° C_a..	68.5	61.5	59.5	60	
53	As cast†.........	85				(7)
54	Before D_c.......		52.5	36		(122)
	D_c 8.1 %........		63	33		
60	790° C_f..........	48.5	21	16	16.5	(110)
	790° Q_o Tp 455° C_a		None	75	74	
	790° Q_o Tp 650° C_a	68.5	51	45.5	47	
63	As cast†.........	141				(7)
68	N 860°..........	41	37.5	39		(110)
	790° Q_o 460° C_a..	78.5	72	73.5		
82	As cast†.........	156.5				(7)

Key No.	Trt.	*CS*	$-100\frac{\Delta l}{l_0}$	Treatment	*CS*	$-100\frac{\Delta l}{l_0}$	Lit.
9	R	35	3	500°/30 C_a	35	3	(26)
	R	70	20	Same	70	21	
	R	105	39	Same......	105	39.5	

Compressive stress† = 157.5 kg/mm² (7)

No.	Treatment	$-100\frac{\Delta l}{l_0}$
1	Cast	62.5
	A 950°	63.5
7	Cast	62
	A 950°	62
18	Cast	56
	A 950°	58.5
21	Cast	51.5
	A 950°	56
29	Cast	52.5
	A 950°	56.5
34	Cast	50
	A 950°	54.5
37	Cast	51
	A 950°	55
49	Cast	47
	A 950°	51.5
53	*A* 950°	45.5
63	*A* 950°	51
73	Cast	33
	A 950°	41
81	Cast	17
	A 950°	53
82	*A* 950°	58.5

* For analyses *v.* p. 484.

† Test piece 1.12 in. × 0.584 in. diam.

TABLE 2, PART III.—TORSION TESTS ON CARBON STEELS

Key No.	Treatment	Dimensions, inches (d = diameter)	*USS**	*TMR*	YP_S	PL_S	EL_S	Twist, degrees (total)	Lit.
1	N..............	2 × 0.5 d			9.5	9	8.5		(90, 110)
	A..............	12.06 × 2.95 d			12	8			
3	R_h..............	2 × [illegible] d	32_c	43	12.5	10			(128)
		5 × 1.75 d	31_c	41.5	13.5	11.5			
4	R_h..............	2 × [illegible] d	32.5_c	43.5	17	16			(65, 128)
	N 900°........	1.75 × [illegible] d	33_c	44	12			1070	
5	N 900°..........	1.75 × [illegible] d	36_c	48	17.5			913	(65)
	Same 700° Q_w..	1.75 × [illegible] d	39_c	52	18.5			971	
	Same 760° Q_w..	1.75 × [illegible] d	41.5_c	55.5	15.5			1028	
	Same 820° Q_w..	1.75 × [illegible] d	42.5_c	57	15.5			1050	
6	Sv..............	1.75 × [illegible] d	35.5_c	47	14			551	(67)
7	Sv..............	1.75 × [illegible] d	40	53.5	18			585	(67)
8	G, Large........	1.75 × [illegible] d	32_c	43		9		350	(67)
	Same, A.........	1.75 × [illegible] d	33.5_c	44.5		17		650	
	G, Small, A......	1.75 × [illegible] d	34.5_c	46		15.5		700	

TABLE 2, PART III.—TORSION TESTS ON CARBON STEELS.—(*Continued*)

Key No.	Treatment	Dimensions, inches (d = diameter)	*USS**	*TMR*	*YPs*	*PLs*	*ELs*	Twist, degrees (total)	Lit.
13	F Sv ∥	1.75 × ⅜ d	37_c	50	14.5			508	(67, 72)
	F Sv ⊥	1.75 × ⅜ d	38_c	51	15			533	
14	A 760° C_a	3.5 × 0.33 d				17			(140)
15	G cast		42.5		24.5	17		460	(68, 95)
	G A 925° C_f		42		18	18		840	
	G N 925° C_a		44		20	17		1025	
	N 850°		43.5_c	58	22.5			548	
19	N 815°	2 × 0.5 d			16	14	14		(110)
	845° Q_w Tp 565° C_a				42.5	36	36		
20	R_h	2 × ⅜ d	42_c	56	24	22			(128)
24	R	1.75 × ⅜ d	46_c	61.5	21.5			518	(67, 72)
	N 820°	1.75 × ⅜ d	46_c	61.5	24.5			434	
	Sv ⊥	1.75 × ⅜ d	44_c	58.5				256	
	Sv ∥	1.75 × ⅜ d	44.5_c	59.5				346	
	Sv ↗	1.75 × ⅜ d	45.5_c	60.5				300	
27	N	1.75 × ⅜ d	$47.5_c^{\dagger}$	63.5		26.5		300	(72)
32	N 845°	1.75 × ⅜ d			24	21	21		(110)
	790° Q_w Tp 650° C_a	1.75 × ⅜ d			None	36.5	37.5		
39	R	1.75 × ⅜ d	58.5_c	78.5	27.5			182	(67)
	N 810°	1.75 × ⅜ d	52.5_c	70	26			320	
58	N 850°	1.75 × ⅜ d	56_c	75.5	29.5			184	(67)
60	790° C_f	2 × 0.5 d			16	11	12		(110)
	790° Q_o Tp 455° C_a	2 × 0.5 d			None	53	54.5		
	790° Q_o Tp 650° C_a	2 × 0.5 d			None	29.5	29.5		
68	N 860°	2 × 0.5 d			28	25.5	25.5		(110)
	790° Q_o W_2 460° C_f				None	56.5	58		
70	A 760° C_f	3.5 × 0.33 d				27			(140)

* Subscript c, Calculated on assumption of uniform stress throughout cross-section.

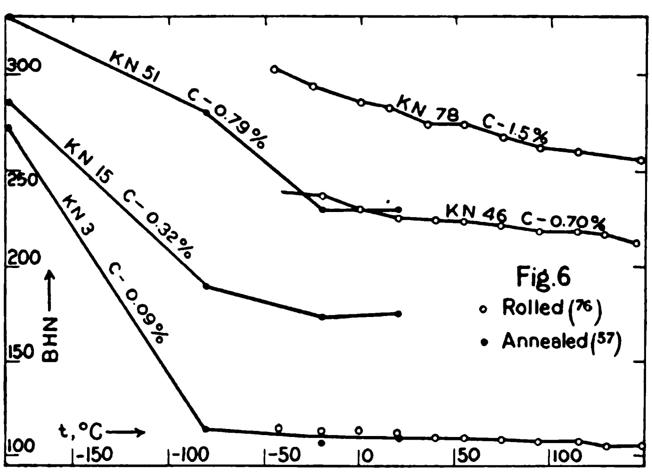


Fig. 6

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS*

Key No.	Treatment	*BHN*†	*ScH*	Lit.
1	Before D_c	105		(18, 62, 110, 118, 122)
	D_c 14.8%	178		
	H_{wk} 71 kg/mm	149	37	
	Normalized	69–121		
	(1½ in. diam.) W 920° Q_w	167		
	(1½ in. diam.) W 920° Q_o	137		
2	As received (*v. also* Fig. 53)	120‡	21	(46)
3	R (*v. also* Fig. 6)	112		(57, 76)
	A (*v. also* Fig. 6)	110		
4	N 900°	95	21	(65)

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.*—(*Continued*)

Key No.	Treatment	*BHN*†	*ScH*	Lit.
5	900° Q_o	143–156		(18, 65, 111)
	Same, Tp 600°	156	(*v. also* Figs. 41, 52)	
	866° Q_w	170		
	A 866°	107		
	N 900°	122	20	
	Same, Tp 700° Q_w	125	22	
	Same, Tp 760° Q_w	146	25	
	Same, Tp 820° Q_w	143	24	
6	As received	96–144‡	22‖	(14, 18, 67, 139)
	N 920°	137		
	920° Q_w	223		
	Same, Tp 760° Q_w	183		
	920° Q_o	170		
7	As received	118–121‡		(67, 111)
	A 858°	111	(*v. also* Fig. 41)	
	858° Q_w	228		
8	Large casting	116		(67)
	Same, A	118		
	Small casting, A	127		
12	Rolled	158	(*v. also* Fig. 41)	(18, 114)
	A 850°	150		
	N 900°	159		
13	N 870° (1½ in. diam.)	143		(18, 67)
	870° Q_w (1½ in. diam.)	196		
	870° Q_o (1½ in. diam.)	179		
	F Sv ∥	128	20–21	
	F Sv ⊥	109	19–20	
	v. Figs. 41 and 53			
14	As received	144	(*v. also* Fig. 41)	(49, 111)
	A 836–900°	134		
	836° Q_w	255		
	836° Q_o	207		
	900° Q_o 650°/120 Q_w	169		
	900° Q_o 650°/120 C_f§	161		
	1020° Q_o 650° Q_w	161		
	1250° Q_o 650/120 Q_w	174		
	1250° Q_o 650/120 C_f§	157		
15	As cast	141	(*v. also* Fig. 6)	(57, 68, 95)
	A 925° C_f	143		
	N 925° C_a	163		
	N 850°	156	27	
	Sv	163		
16	A (*v.* Fig. 41)	161		(103)
17	F Sv ∥	147	27	(67)
	F Sv ⊥	143	28	
	F Sv ↗	143	28	
18	900° Q_o Tp 2 h 600° C_a	173		(81)
	900° Q_o Tp 2 h 650° Q_w	161		
	900° Q_o Tp 2 h 650° C_a	158		
19	N 815°	132		(49, 68, 72, 110)
	N 850°	156		
	A 850°	145		
	900°/60 C_f	157		
	900°/60 C_a, 760°/60 Q_o	180		
	Same, Tp 650°/120 Q_w	162		
	Same, Tp 650°/120 C_f §	150		
	900° Q_o, 650°/2 h Q_w	192		
	900° Q_o, 650°/2 h C_f§	178		

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.*—(*Continued*)

Key No.	Treatment	*BHN*†	*ScH*	Lit.
19	900°/30, C_a Tp 5 h, 600° C_a	134–160		
	680°	135		
	750°	137		
24	N 820°	170	29	(67, 72)
	Sv ⊥	170		
	Sv ‖	179		
	Sv ↗	174		
25	N 870° (*v.* Figs. 42 and 52)	192		(18)
27	As received	170		(110, 111)
	A 816–819°	158	(*v. also* Fig. 42)	
	816–819° Q_w	655		
	816–819° Q_o	261		
	775° Q_w 650° C_f	197		
30	R	228	36	(62)
32	As received	179‡		(92, 110)
	N 845°	193	24	
	790° Q_w 650° C_a	227	30	
33	*v.* Fig. 42			
39	R	252	40	(59, 62, 67, 111, 139)
	N 810°	223	35	
	A 809°	183	27‖	
	809° Q_w	578	(*v. also* Fig. 42)	
	809° Q_o	311		
40	F W_2 C_a	241		(142)
41	*v.* Fig. 53			
46	R	226	(*v. also* Figs. 6, 29)	(76, 103)
	A	174		
	790° Q Tp 420°	418		
	841° Q Tp 420°	430		
	887° Q Tp 420°	437		
47	R	240	(*v. also* Fig. 42)	(111)
	A 800°	217		
50	R	273	50	(62)
51	As received	255‡	(*v. also* Fig. 42)	(25, 57)
	Annealed	230		
54	Before D_c	268	(*v. also* Fig. 44)	(111, 122)
	D_c 8.1%	293		
56	A	181	(*v. also* Fig. 29)	(103)
	717° Q_w	217		
58	N 850°	286	40	(67)
59	N	286		(68)
60	790° C_f	162	23	(110)
	790° Q_o 650° C_a	227	31	
	790° Q_o 450° C_a	380	51	
61	*v.* Fig. 53			
63	875° Q_w Tp 450°	402		(65)
	875° Q_o Tp 450°	402		
64	N 815°	217	32	(44)
	780°/30 Q_w Tp 538°/15	258	42	
	843°/30 Q_w	290	46	
	788°/30 Q_o	321	48	
	788° Q_{salt}¶	286	40	
	788° Q_{Pb}**	233	34	
	843° Q_{Pb}††	263	34	
	843°/30 Q_o Tp 538°	376	53	
	843°/300	421	58	
	760°/30	313	43	
	760°/300	387	58	

TABLE 2, PART IV.—HARDNESS OF CARBON STEELS.*—(*Continued*)

Key No.	Treatment	*BHN*†	*ScH*	Lit.
64	780°/30 Q_w Tp 538°/15	340	54	
	843°/30 Q_w	340	48	
	788°/30 Q_o	329	48	
	788° Q_{salt}¶	291	41	
	788° Q_{Pb}	266	37	
	760° 30 min Q_o Tp 538°/20 C_o	288	43	
	788°	329	48	
	816°	364	52	
	871°	350	48	
	Last 9 samples wet ground after treatment (*v. also* Fig. 43)			
65	800° Q_w	600		(120)
66	As received	277‡		(92)
67	A (*v.* Fig. 29)	176		(103)
68	N	224	31	(110)
	790° Q_o 460° C_a	369	45	
69	As received	288		(111)
	A 790°	196		
	790° Q_w	555		
	790° Q_o	402		
72	N	286		(37)
	F 900–800° A‡‡	189		
	F 750–700° A§§	179		
76	As received	321	(*v. also* Fig. 44)	(25, 111)
	A 790°	202		
	790° Q_w	460		
78	R (*v.* Fig. 6)	285		(76)

* For analyses *v.* p. 484.
† 10 mm ball; 3000 kg load.
‡ Ludwik cone hardness (90° cone, 3000 kg load): specimens as received.

Key No.	2	6_a	6_b	7	32	51	66	(92)
LCH	130	101	131	140	195	290	330	

a, Calculated from diameter of impression. b, Calculated from depth.
§ C_f 1°/m.
‖ Turner Scratch Test: No. 6 (as received) = 21; No. 39 (A 809°) = 24 (139).
¶ 788°/30 Q_{salt} 538°/15 C_o.
** 788°/30 Q_{Pb} 538°/15 C_o.
†† 843°/30 Q_{Pb} 538°/30 C_o.
‡‡ A 750°/5 h 670°/3 h.
§§ A 670°/4 h.

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS*

Key No.	Treatment	*IS* (Izod)	*IS* (other methods)	Lit.
1	N	3.9	16.6_v, 2.7_s	(18, 68, 110, 118)
	920° Q_w†	7.0		
	920° Q_o†	12.4		
2	As received	6.9	2.9_w, 23_y	(64)
3	A		8.5_w	(33)
4	N 900°	11.2		(65)
5	(*v.* Figs. 47 and 52)		IS_v	(18, 65)
	N 900°	11.6	17.0	
	900° Q_w†	10.4	21.5	
	900° Q_o†	13.0	18.0	
	Same, Tp 600°	13.3	17.5	

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS.*—(*Continued*)

Key No.	Treatment	IS (Izod)	IS (other methods)	Lit.
6	As received	4.8	IS_v	(67, 89)
	N 920°†	11.1	14.3	
	920° Q_w†	3.3	4.4	
	Same, Tp 760° Q_w	5.9	5.7	
	920° Q_o†	12.7	16.3	
	v. also Fig. 17		IS_w	
	A 925°		8.5‡	
	900° Q_o 760°, Q_o, Tp 260° C_a		123.5‡	
7	As received	3.5		(67)
8	Castings (large)	0.9		(67)
	Same, A	2.9		
	Small, A	2.6	1.2	
12	(*v. also* Fig. 47)		IS_v	(18)
	N 900°†	6.3	6	
	900° Q_w†	1.8	1.9	
	900° Q_o†	4.3	3.5	
13	(*v. also* Fig. 48)			(18, 67)
	N 870°†	3.6	3.1	
	870° Q_w†	2.2	2.5	
	870° Q_o†	2.8	3.2	
	F Sv ∥	2.5	0.8_w, 7_y	
	F Sv ⊥	1.8	1.1_w	
			IS_x§	
14	900° C_f	1.5	4.7	(49)
	900°/1 h C_a, 760°/1 h Q_o	5.1	7.4	
	Same, 650°/2 h Q_w ∥	5.2	12.3	
	Same, 650°/2 h C_f	5.9	9.6	
	900°/1h Q_o, 650°/2h Q_w	5.1	8.5	
	Same, but C_f∥	5.4	9.0	
	1020° Q_o, 650°/2 h Q_w	1.7	3.3	
	1250° Q_o, 650°/2 h Q_w	0.8	1.9	
	1250° Q_o, 650°/2 h C_f	0.5	1.8	
15	As cast	0.8		(33, 65, 95)
	N 925° C_a	2.5		
	A 925° C_f	1.8		
	N 850°	4.5	IS_w	
	A		5.1	
17	A 900° (*v.* Fig. 18)		4.3	(89)
18	900° Q_o Tp:			(81)
	600°/2 h C_a	3.3		
	650°/2 h Q_w	4.4		
	650°/2 h C_a	4.0		
19	N	4.3	IS_x§	(49, 68, 72)
	900°/1 h C_f	1.8	4.0	
	900°/1 h C_a, 760°/1 h Q_o	3.3	5.9	
	Same, 650°/2h Q_w	2.9	6.4	
	Same, 650°/2h C_f ∥	3.3	7.0	
	900° Q_o, 650°/2 h Q_w	2.5	6.9	
	900° Q_o, 650°/2 h C_f∥	2.1	5.6	
	900°/30 C_a:			
	Tp 600° 5 h C_a	4.3		
	Tp 680° 5 h C_a	4.7		
	Tp 750° 5 h C_a	5.0		
24	N 820°	3.9	IS_w	(67, 72)
	Sv ⊤	0.8	0.4	
	Sv ∥	0.5	0.4	
	Sv ↗	0.8	0.4	
25	N 870°†	4.3	3.5_v	(18)
	v. Figs. 48 and 52			
27	N	2.0	IS_x	(72, 110)
	775° Q_w 650° C_f		3.1	
32	N 845		1.8	(110)
	790° Q_w 650° C_a		3.0	
33	790° Q_o		1.6	(109)
	Same, Tp 205° C_a		1.2	
	Same, Tp 315° C_a		2.0	
	Same, Tp 425° C_a		1.6	
	Same, Tp 540° C_a		3.1	
	Same, Tp 650° C_a		4.2	
	Same, Tp 760° C_a		2.7	
39	As received	0.7		(67)
	N 810°	1.1		
			IS_w	
54	A 845°		3.3‡	(89)
	800° Q_o 450° C_f		9.0‡	
	v. also Fig. 19			
58	N 850°	0.3		(67)
59	N	0.3		(68)
			IS_s	
60	790° C_f		0.3	(110)
	790°Q_o, Tp 650° C_a		0.5	
	790°Q_o, Tp 455° C_a		0.6	
63	875° Q_w, Tp 450°	1.5		(65)
	875° Q_o, Tp 450°	1.7		
			IS_v	
64	780°/30 Q_w, Tp 538°/15	0.3	0.4	(44)
	788°/30 Q_o, Tp 538°/15	0.3	0.4	
	I¶	0.5	0.5	
	II	0.4	0.4	
	843°/30 Q_o, Tp 538°	0.4	0.4	
	843°/5 h Q_o, Tp 538°	0.4	0.5	
	760°/30 Q_o, Tp 538°	0.4	0.4	
	Above samples not wet ground			
	780°/30 Q_w, Tp 538°/15	0.3	0.4	
	788°/30 Q_o, Tp 538°/15	0.3	0.4	
	I¶	0.5	0.5	
	II	0.4	0.4	
	760° 30 Q_o, Tp 538°	0.3	0.4	
	816° 30 Q_o, Tp 538°		0.5	
	843° 30 Q_o, Tp 538°	0.4	0.4	
	871° 30 Q_o, Tp 538°	0.4	0.5	
	788° Q_w, Tp 538°	0.3	0.4	
	788° Q_w, Tp 649°	0.3	0.4	
	788° Q_w, Tp 704°	0.7	0.8	
	788° Q_w, Tp 760°	0.3	0.4	
	788° Q_o, Tp 316°	0.4	0.6	
	788° Q_o, Tp 538°	0.3	0.5	
	788° Q_o, Tp 649°	0.3	0.5	
	788° Q_o, Tp 704°	0.4	0.4	
	843° Q_o, Tp 316°	0.5	0.5	
	843° Q_o, Tp 649°	0.5	0.6	
	843° Q_o, Tp 704°	0.6	0.8	
	843° Q_o, Tp 760°	0.4	0.4	

TABLE 2, PART V.—IMPACT STRENGTH OF CARBON STEELS.*—(*Continued*)

Key No.	Treatment	*IS* (Izod)	*IS* (other methods)	Lit.
64	843° Q_o, Tp 704° { 30 m	0.6	0.4_v	
	5 h	0.4	0.6_v	
	Above samples wet ground after treatment			
68	N 860°		0.3_s	(110)
	790° Q_o 460° C_a		0.3_s	
72	N	0.2		(37)
	F 900–800°, A 750°/5 h, A_2 670°/3 h	0.2		
	F 750–700°, A 670°/4 h	0.2		

* For meaning of subscripts *v.* p. 396.
† Bars 1⅛ in. diam.
‡ Test piece 30 mm², diam. of bottom of notch = 4 mm.
§ Tested in the Guillery machine.
‖ Cooled at 1° per minute.
¶ I = 788°/30 Q_{salt} 538°/15 Q_o.
II = 788°/30 Q_{Pb} 538°/15 Q_o.

TABLE 3.—MECHANICAL PROPERTIES OF CAST IRON*†
v. also Figs. 7, 7a, 8, and 20

Key No.	*ScH*	*UTS*	*BMR*‡	Lit.	Key No.	*ScH*	*UTS*	*BMR*‡	Lit.
84	52–58	17	28_l	(32)	92	56–61	20	$43–59_l$	(32)
85	62	12.5	28.5_l	(32)	93	‖	26.5	41_m	(137)
86	54–62	18.5	29_l	(32)	94	31	23.5	34_l	(32)
87		19	39.5_m	(135)	95	56–60	18.5	$42–56_l$	(32)
88	40–43	9–19	34_l	(32)	96	40–60	14–29	38_l	(32)
89	63	26	45_l	(32)	97	31–40	22.5	34_l	(32)
90	48–53	26§	34.5_l	(32)	98	65	26	47_l	(32)
91	40–45	20–31	$28–50_l$	(32)	99	50	21	46_l	(32)

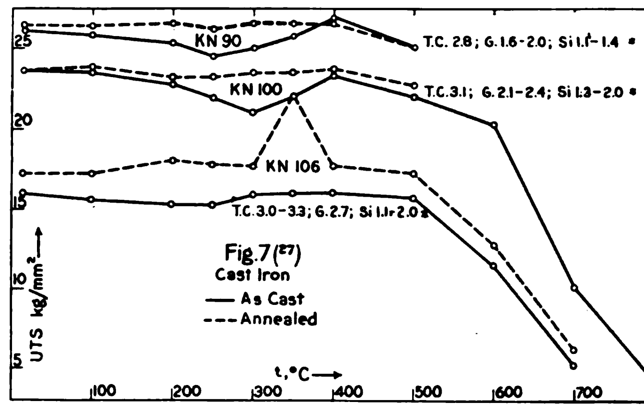
Key No.	Hardness		Tensile properties			Compression properties		Bending	Lit.
	BHN	*ScH*	*UTS*	*El*	*RA*	*UCS*	PL_C	*BMR*‡	
100	187	37–50	24§			100¶	50	34–47	(27, 32, 124, 135)
101**			30–46	6_a – 2_a††					(63)
102**	101–145		25–41§	15.0_a – 4.5_a††		IS_u = 0.1			(63, 68)
103		57	20.5					41.5_l	(32)
104		58	24.5					49_l	(32)
105		43	26.5					40_l	(32)
106	160–220	38	16–28§	*ca.* 0	‡‡	63–105		36	(21, 78, 124, 145)
107	192–200		23.5§					35_m	(130, 137)
108	203–213	40–50	} 21			Machined		32.5_o	(32, 135, 139)
	TSH = 36					Unmachined		45_m	
109	207–217	33–36	16.5	0.2	0.0			31	(68, 145)
110	180		22					33.5_m	(137)
111	149–207		18			64.5	34.5	33.5_n	(21, 124)
112	160–217		21					$27–47_m$	(137)
113	192		22.5					37.5_m	(137)
114	131–176		16			68	27	31.5_n	(21, 124)
115			19§						(130)
116			27					54_m	(135)
117	110–151	30–40	16–21			44–58			(131)
118	105–143	24§§	15	(*PL* = 7)		61¶	32.5	30_n	(124)

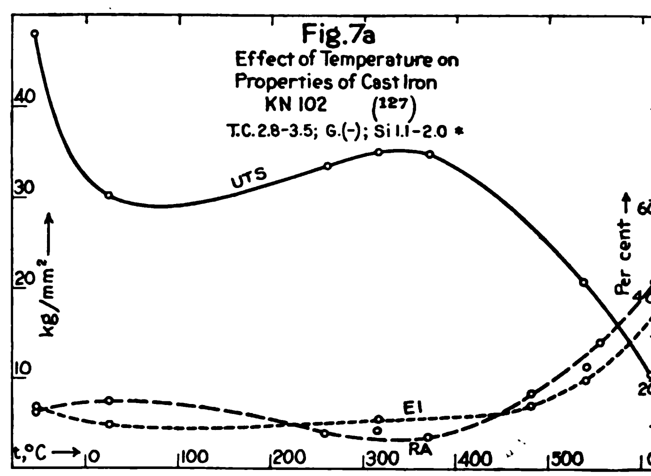
* For analyses *v.* p. 485. For effect of Mn and Si content on cast iron *v.* p. 525.
† All specimens "as cast" except where noted.
‡ Meaning of subscripts to values of *BMR*: l = 1 in. sq., span 12 in.; m = 1¼ in. diam., span 12 in.; n = 10 × 10 × 65 mm, span 30 mm; o = 0.862 in. sq., span 12 in.
§ For high temperature tests, *v.* Figs. 7, 7a, 8 and 20.
‖ *BHN* = 175.
¶ 16 mm × 16 mm diam.
** No. 101, Trt = A 840–880°; *YP* = 19–28; No. 102, Trt = A 770–840°, *YP* = 16–31.5.
†† For both *El* and *RA*.
‡‡ Torsion tests: Soft, (*BHN* = 92), *USS* = 14.5; Fine grained (*BHN* = 150), *USS* = 24; Hard fine grained (*BHN* = 217), *USS* = 28 } *TMR* = 24.5 (78).
§§ *TSH* = 21–23.

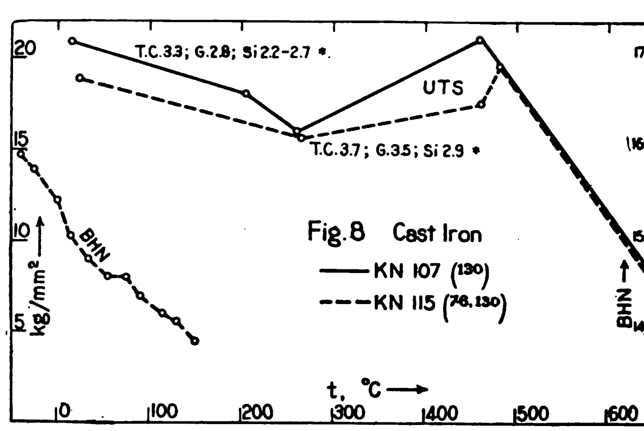
EFFECT OF ANNEALING ON TENSILE STRENGTH OF CAST IRON (27)

A, *t*° C	100	200	250	300	350	400	500	600	700
K. No. 90, *UTS* =	26	25	24.5	25	26	27	25		
K. No. 106, *UTS* =	16.5	16.5		17		17	17	15	13

		K. No. 90	K. No. 100	K. No. 106
W 25 times to 450°	*UTS* =	23.5	21	15
W 25 times to 550°	*UTS* =	22	20.5	12







* T.C. = total carbon; G. = graphite.

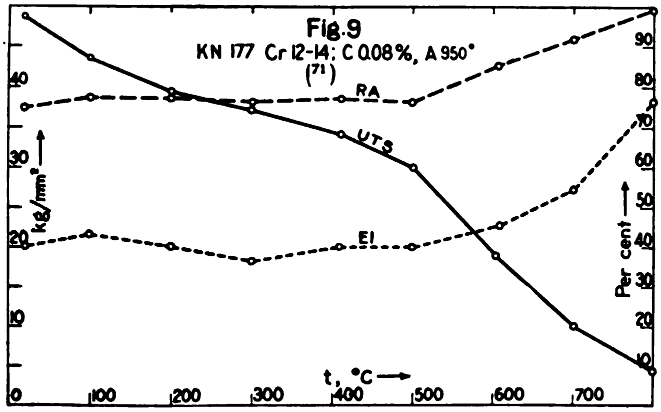


Fig.9
KN 177 Cr 12-14; C 0.08%, A 950°
(71)
RA
UTS
El
kg/mm²
Per cent
t, °C

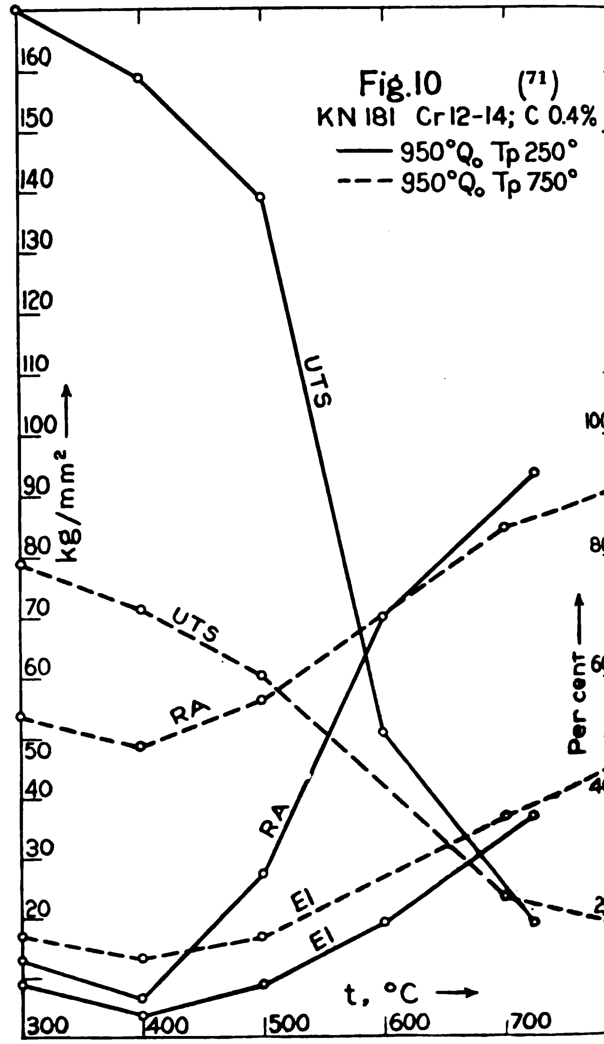


Fig.10 (71)
KN 181 Cr 12-14; C 0.4%
950°Q₀ Tp 250°
950°Q₀ Tp 750°
UTS
RA
El
kg/mm²
Per cent
t, °C

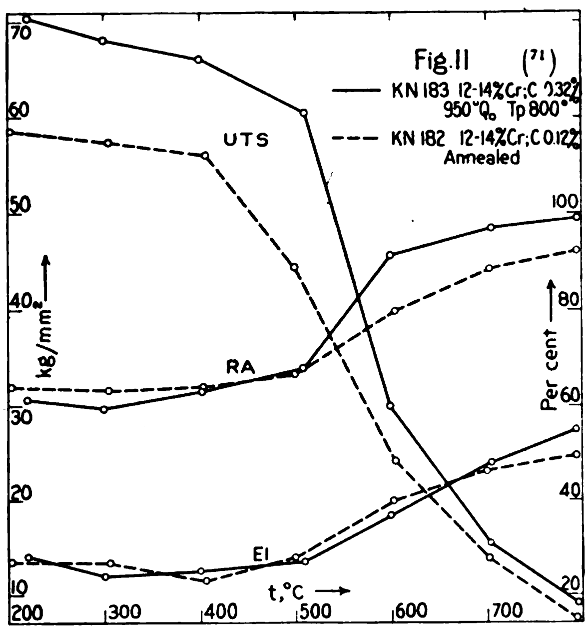


Fig.11 (71)
KN 183 12-14%Cr;C 0.32% 950°Q₀ Tp 800°
KN 182 12-14%Cr;C 0.12% Annealed
UTS
RA
El
kg/mm²
Per cent
t, °C

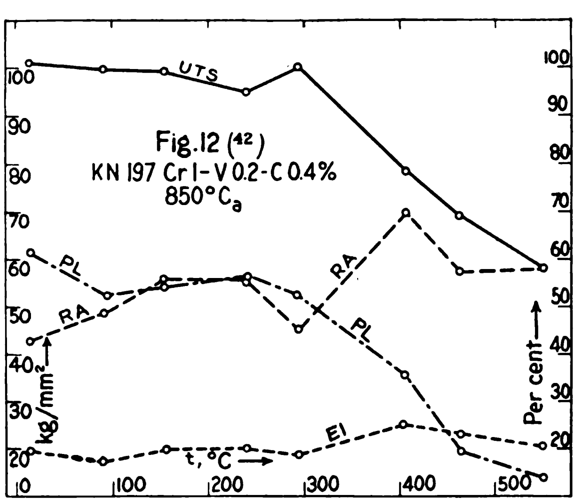


Fig.12 (42)
KN 197 Cr 1-V 0.2-C 0.4%
850° Ca
UTS
PL
RA
El
kg/mm²
Per cent
t, °C

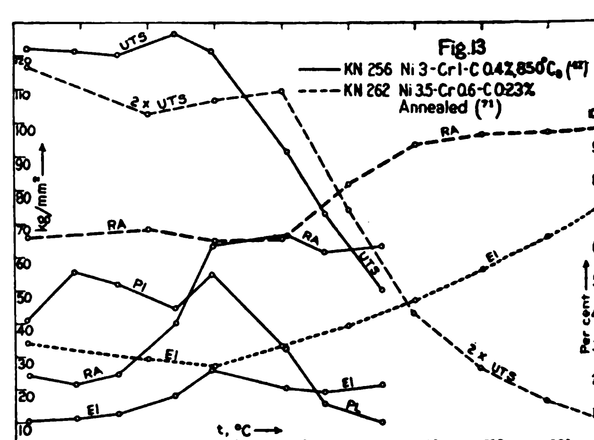


Fig.13
KN 256 Ni 3-Cr 1-C 0.4%, 850°Ca
KN 262 Ni 3.5-Cr 0.6-C 0.23% Annealed (71)
UTS
2 x UTS
RA
Pl
El
kg/mm²
Per cent
t, °C

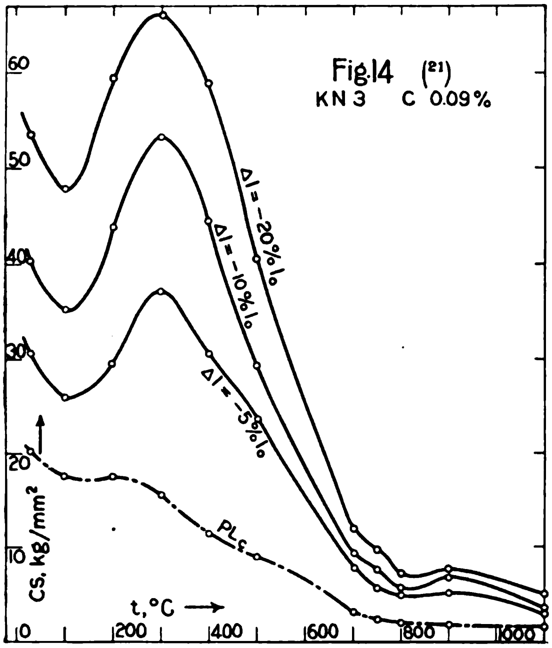


Fig. 14 (21)
KN 3 C 0.09%

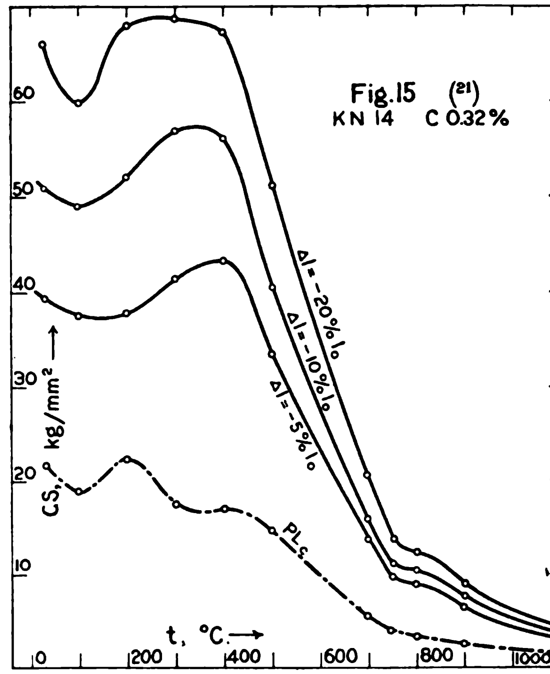


Fig. 15 (21)
KN 14 C 0.32%

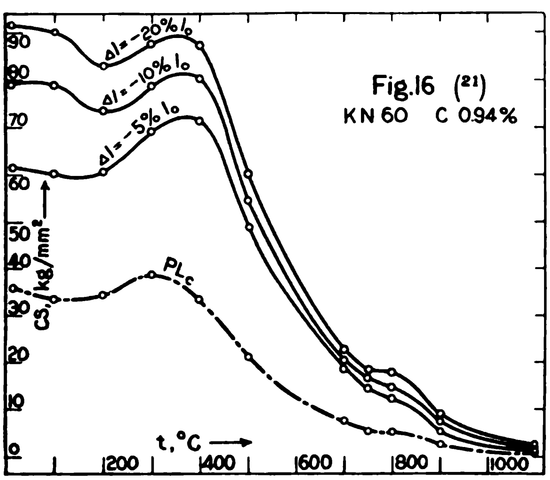


Fig. 16 (21)
KN 60 C 0.94%

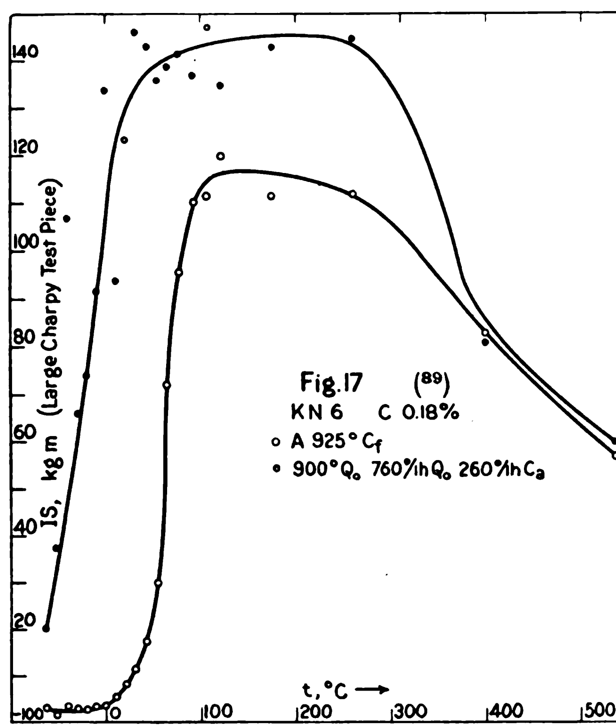


Fig. 17 (89)
KN 6 C 0.18%

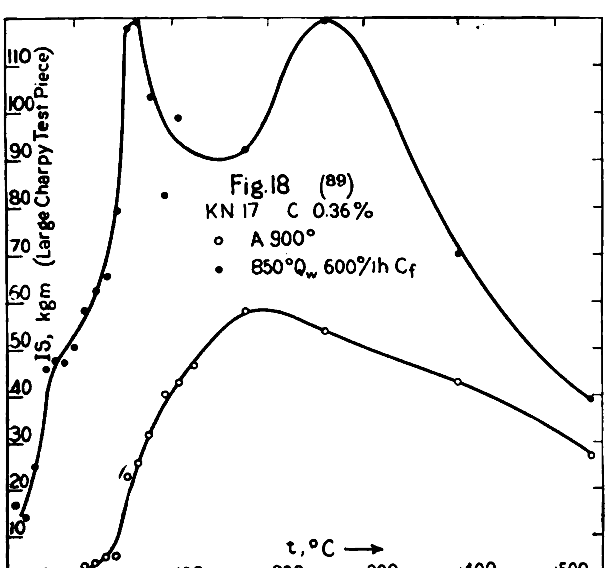


Fig. 18 (89)
KN 17 C 0.36%

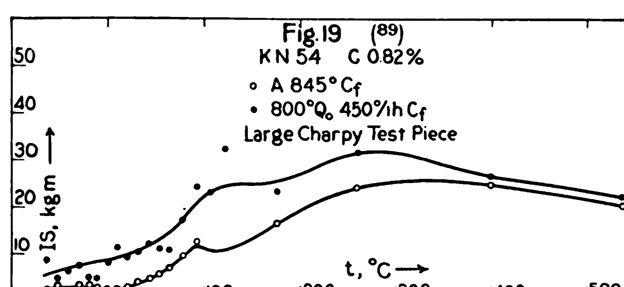
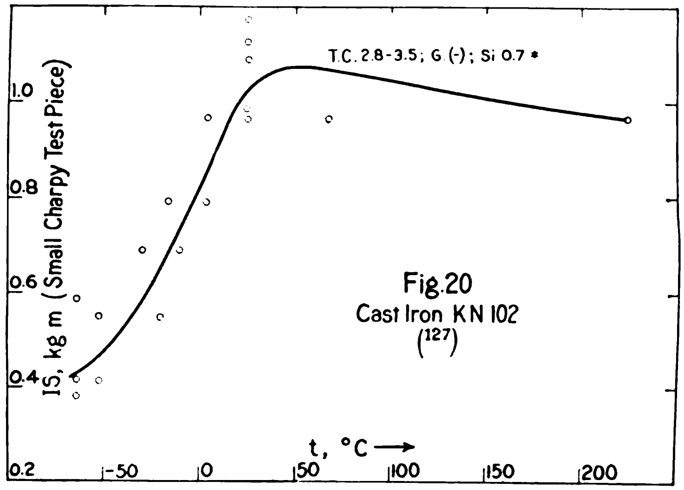
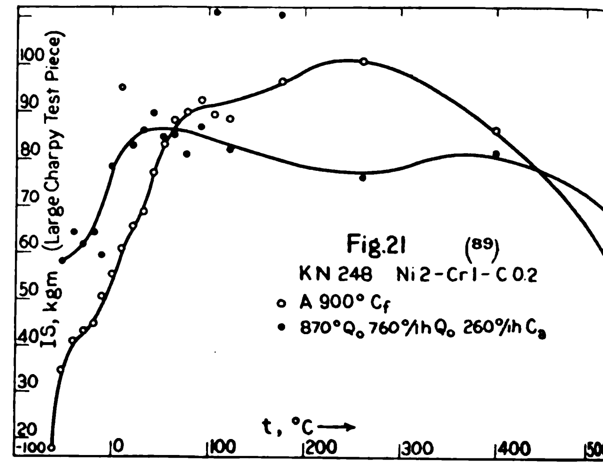
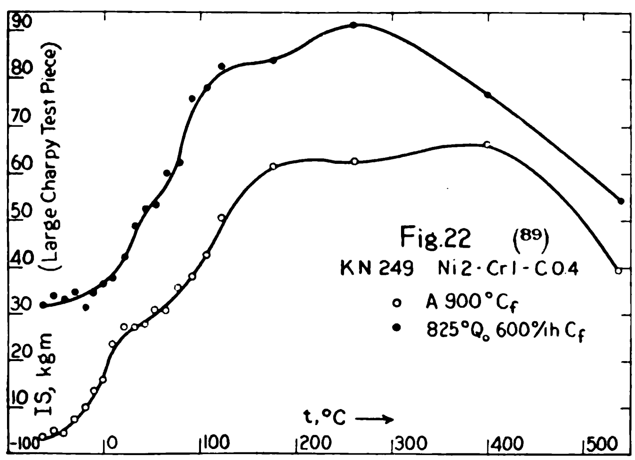


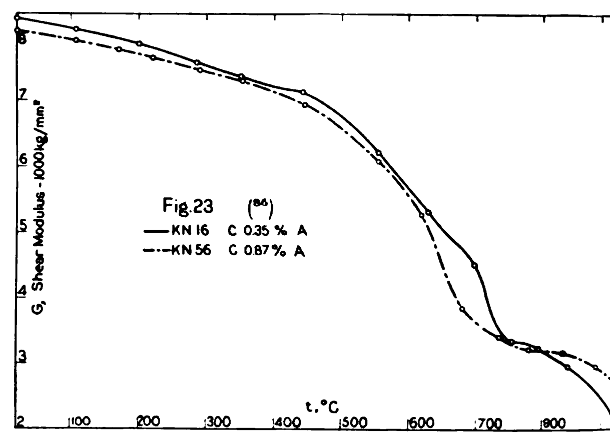
Fig. 19 (89)
KN 54 C 0.82%

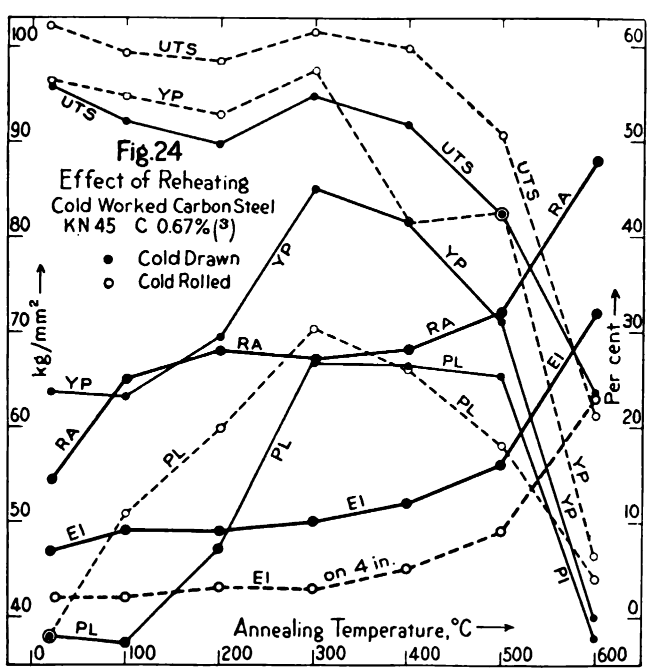


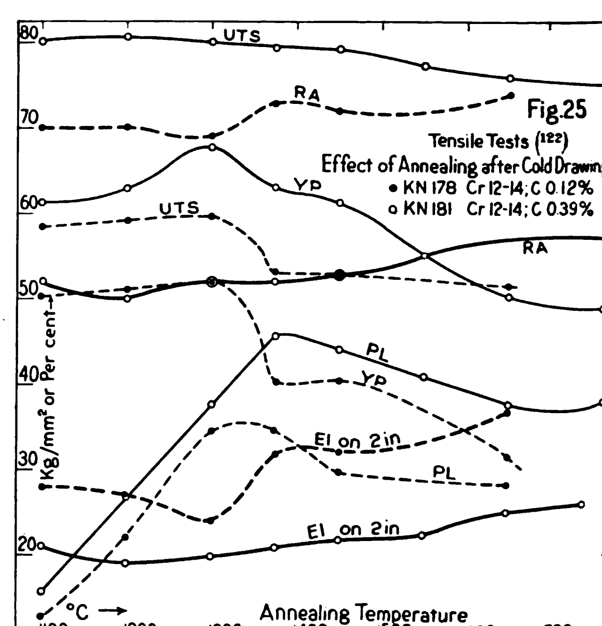
* T.C. = total carbon; G. = graphite.











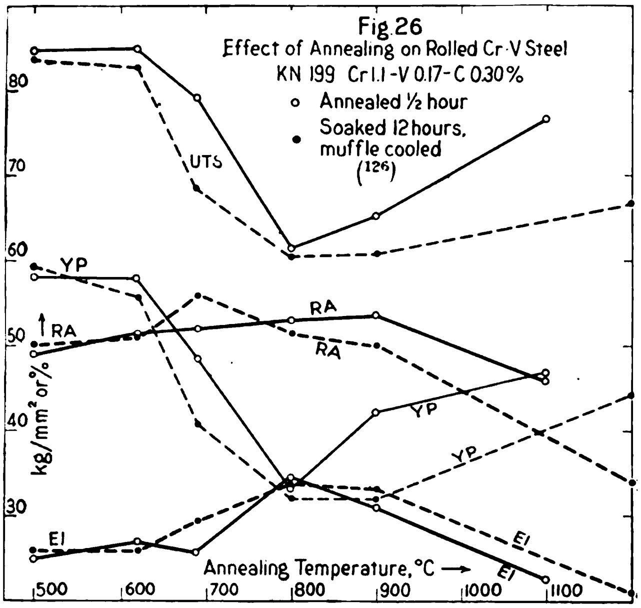


Fig.26
Effect of Annealing on Rolled Cr-V Steel
KN 199 Cr 1.1-V 0.17-C 0.30%
Annealed ½ hour
Soaked 12 hours, muffle cooled
(126)
UTS
YP
RA
El
kg/mm² or %
Annealing Temperature, °C
500 600 700 800 900 1000 1100

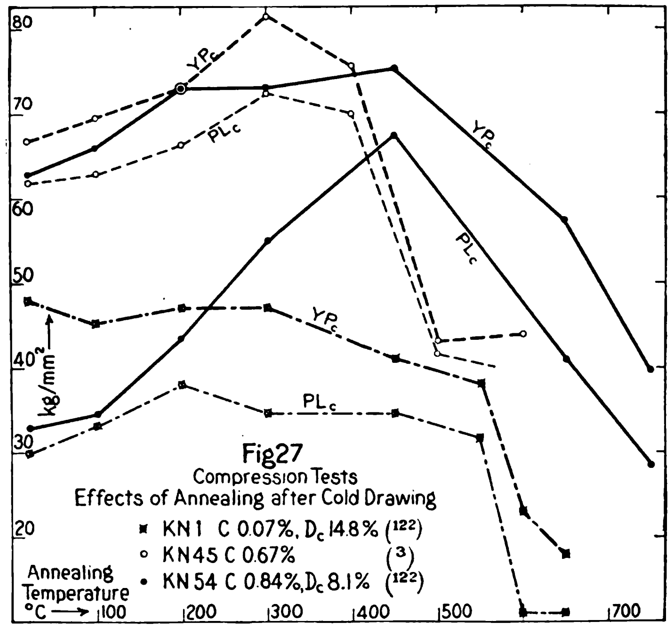


Fig27
Compression Tests
Effects of Annealing after Cold Drawing
KN 1 C 0.07%, Dc 14.8% (122)
KN 45 C 0.67% (3)
KN 54 C 0.84%, Dc 8.1% (122)
YPc
PLc
kg/mm²
Annealing Temperature °C
100 200 300 400 500 700

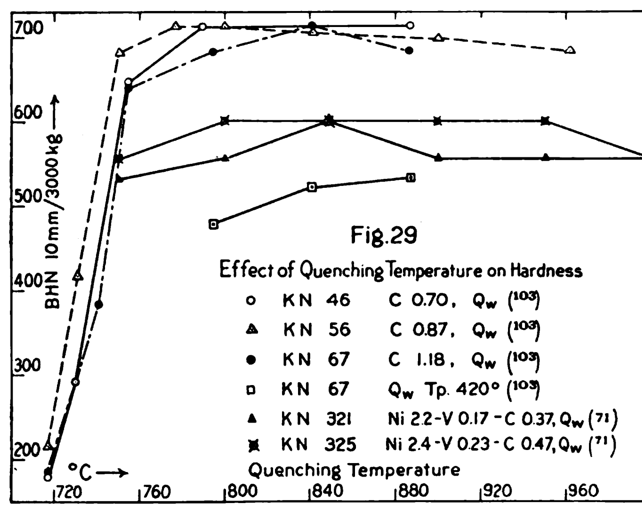


Fig.29
Effect of Quenching Temperature on Hardness
KN 46 C 0.70, Qw (103)
KN 56 C 0.87, Qw (103)
KN 67 C 1.18, Qw (103)
KN 67 Qw Tp. 420° (103)
KN 321 Ni 2.2-V 0.17-C 0.37, Qw (71)
KN 325 Ni 2.4-V 0.23-C 0.47, Qw (71)
Quenching Temperature
BHN 10mm/3000kg
°C
720 760 800 840 880 920 960

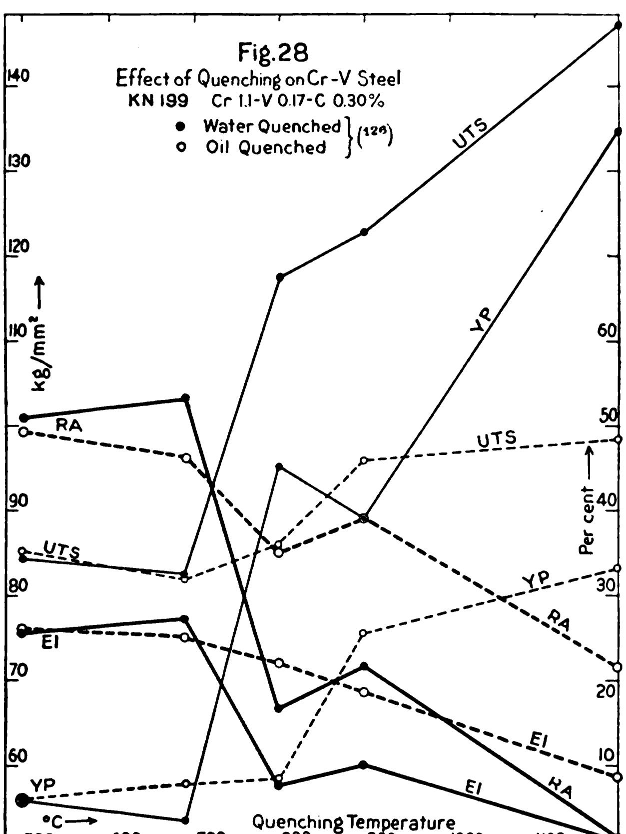


Fig.28
Effect of Quenching on Cr-V Steel
KN 199 Cr 1.1-V 0.17-C 0.30%
Water Quenched
Oil Quenched
(126)
UTS
YP
RA
El
kg/mm²
Per cent
Quenching Temperature
°C
500 600 700 800 900 1000 1100

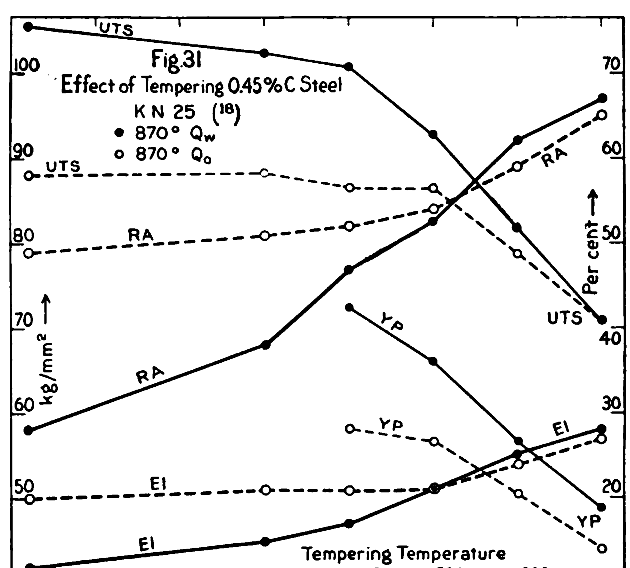


Fig.31
Effect of Tempering 0.45% C Steel
KN 25 (18)
870° Qw
870° Qo
UTS
RA
YP
El
kg/mm²
Per cent
Tempering Temperature
°C
100 200 300 400 500 600

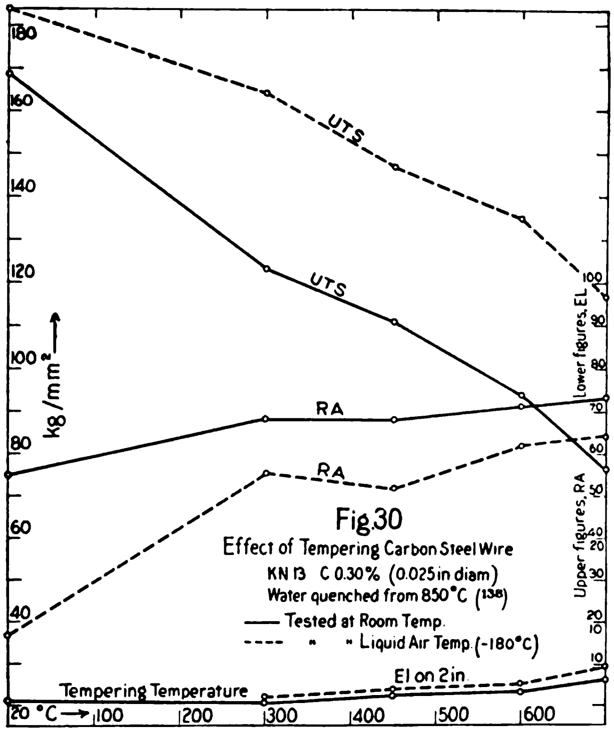


Fig. 30
Effect of Tempering Carbon Steel Wire
KN 13 C 0.30% (0.025 in diam)
Water quenched from 850°C (138)
—— Tested at Room Temp.
- - - - " " Liquid Air Temp. (-180°C)

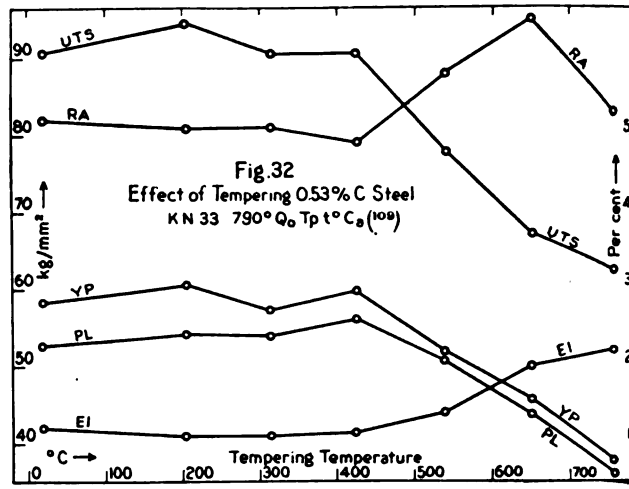


Fig. 32
Effect of Tempering 0.53% C Steel
KN 33 790° Q_o Tp t° C_a (109)

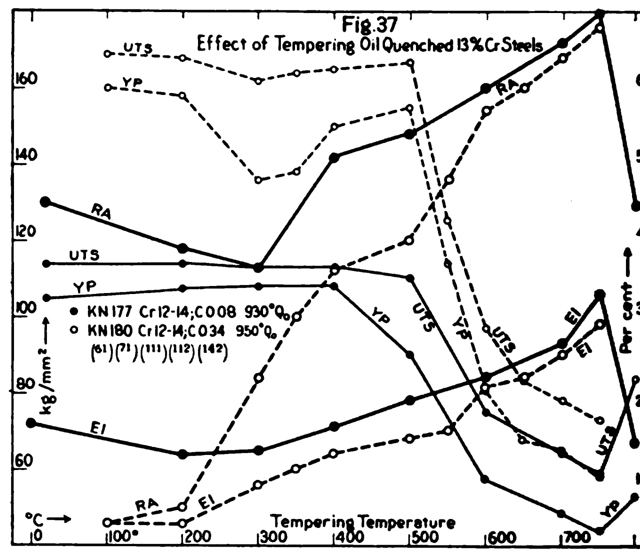


Fig. 37
Effect of Tempering Oil Quenched 13% Cr Steels
• KN 177 Cr 12-14; C 0.08 930° Q_o
○ KN 180 Cr 12-14; C 0.34 950° Q_o
(61) (71) (111) (112) (142)

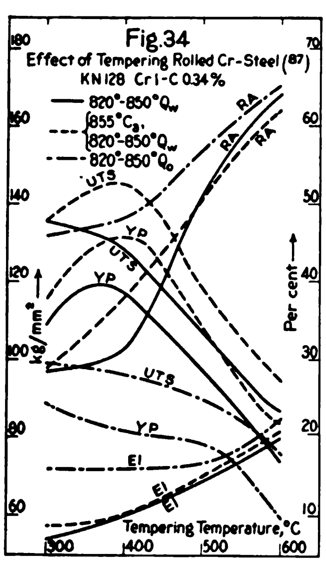


Fig. 34
Effect of Tempering Rolled Cr-Steel (87)
KN 128 Cr 1-C 0.34%
—— 820°-850° Q_w
- - - {855° C_a, 820°-850° Q_w}
-·-·- 820°-850° Q_o

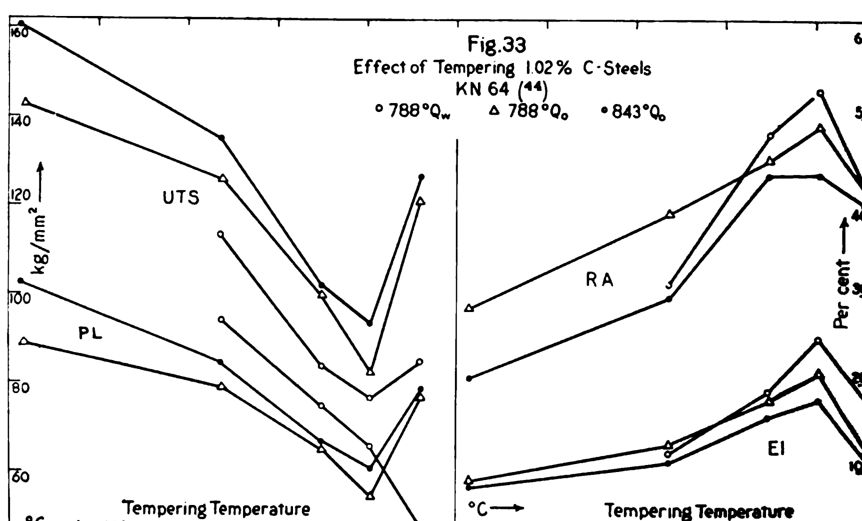


Fig. 33
Effect of Tempering 1.02% C-Steels
KN 64 (44)
○ 788° Q_w △ 788° Q_o • 843° Q_o

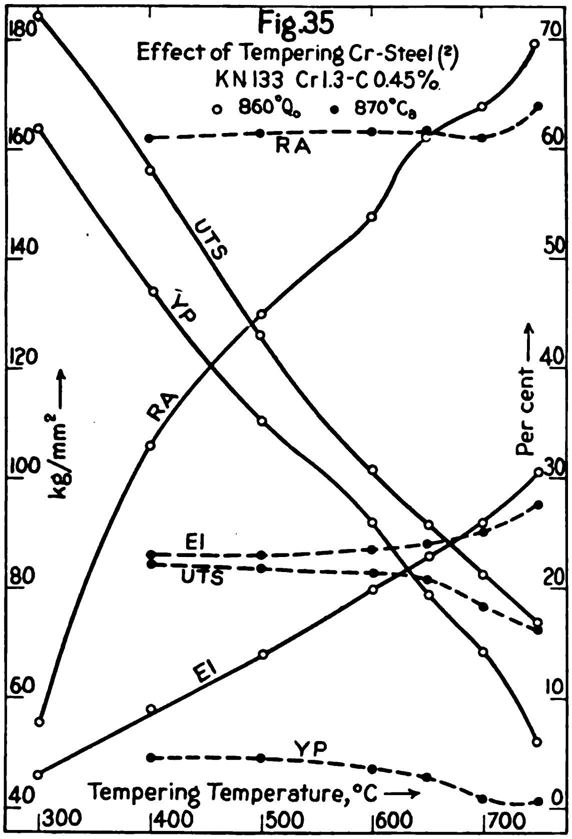


Fig.35
Effect of Tempering Cr-Steel (2)
KN 133 Cr 1.3-C 0.45%

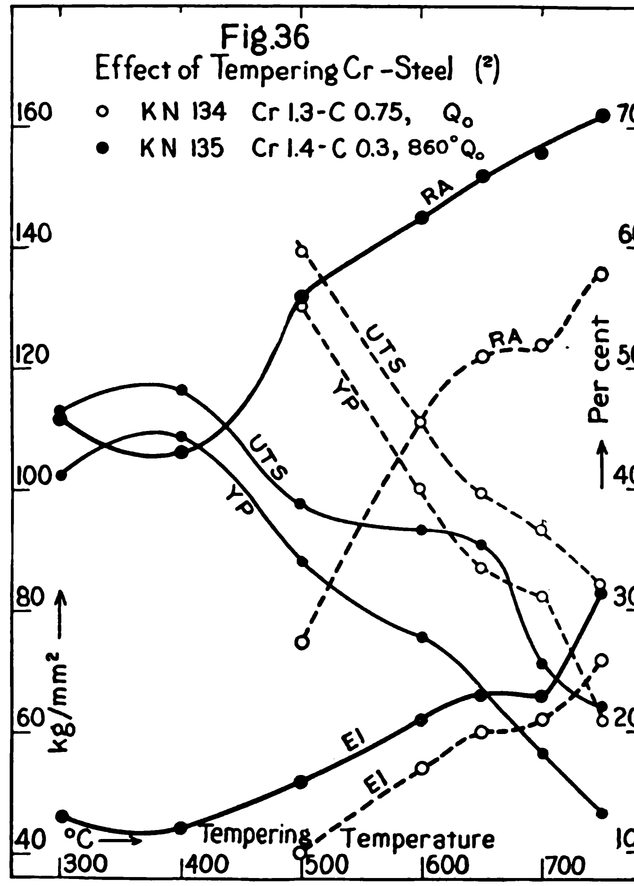


Fig.36
Effect of Tempering Cr-Steel (2)

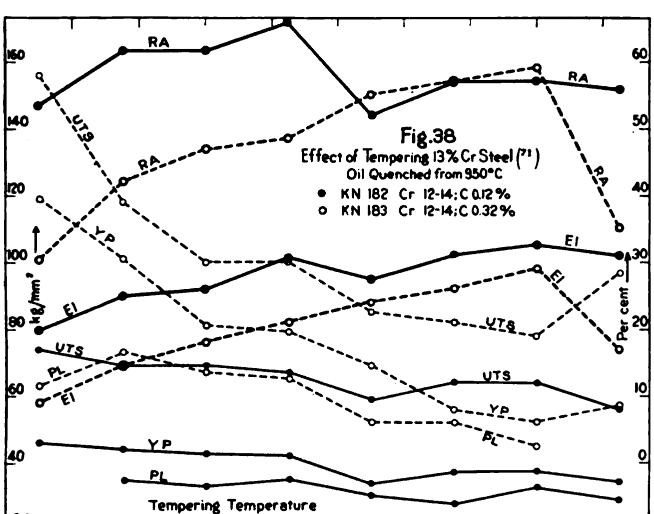


Fig.38
Effect of Tempering 13% Cr Steel (71)
Oil Quenched from 950°C

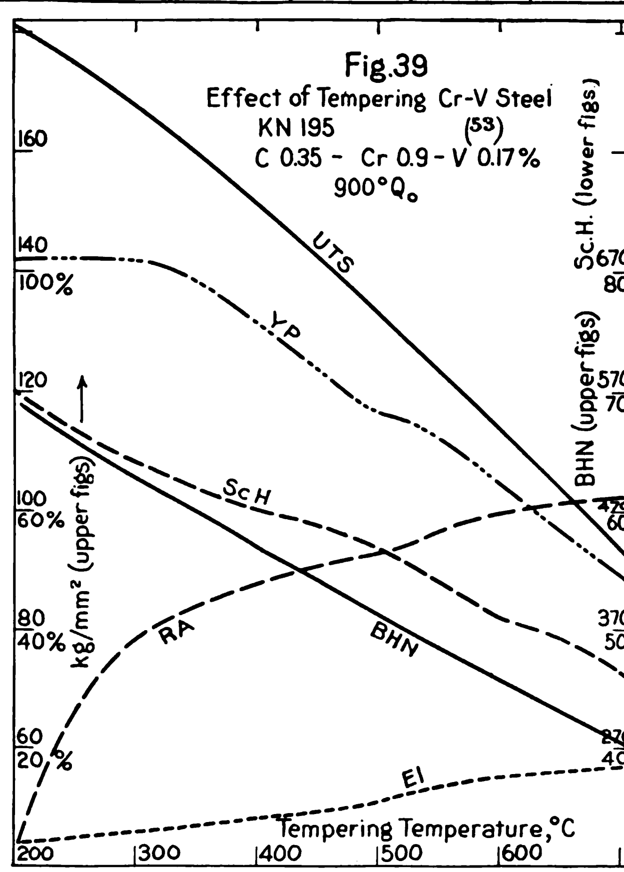


Fig.39
Effect of Tempering Cr-V Steel
KN 195 (53)
C 0.35 - Cr 0.9 - V 0.17%
900°Q_o

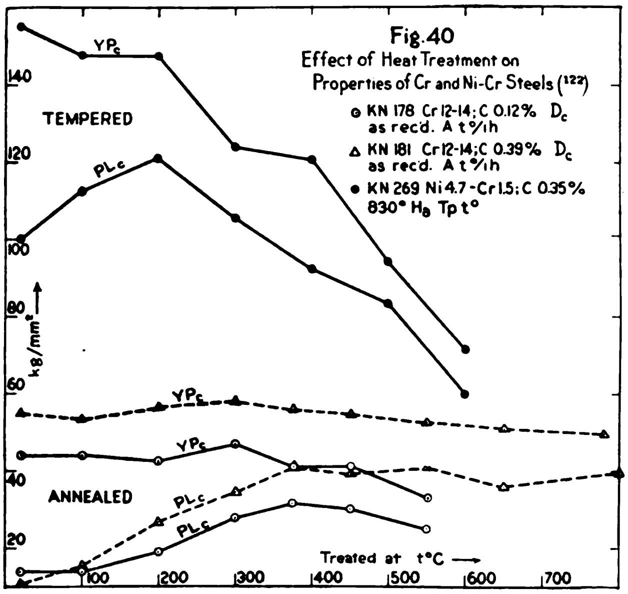


Fig. 40
Effect of Heat Treatment on Properties of Cr and Ni-Cr Steels (122)
KN 178 Cr 12-14; C 0.12% Dc as rec'd. A t°/1h
KN 181 Cr 12-14; C 0.39% Dc as rec'd. A t°/1h
KN 269 Ni 4.7-Cr 1.5; C 0.35% 830° Ha Tp t°
TEMPERED
ANNEALED
YPc
PLc
kg/mm²
Treated at t°C

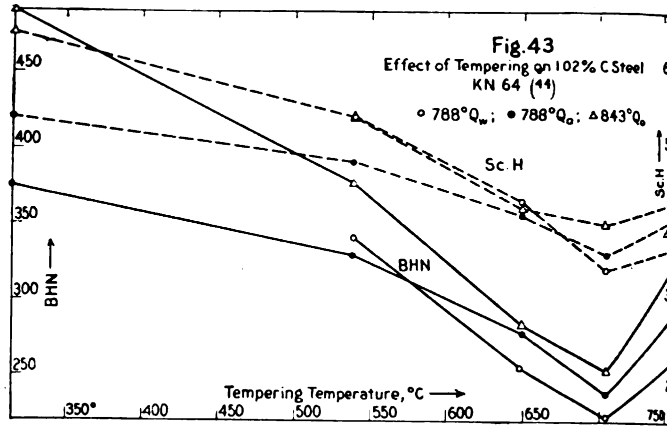


Fig. 43
Effect of Tempering on 1.02% C Steel KN 64 (44)
788°Qw; 788°Qo; 843°Qo
Sc.H
BHN
Tempering Temperature, °C

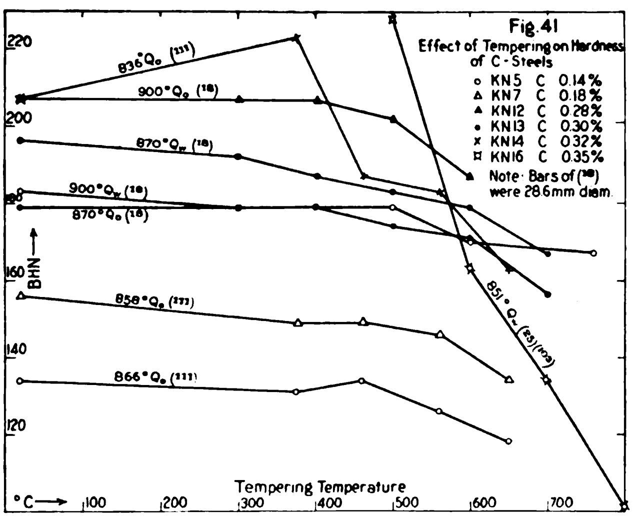


Fig. 41
Effect of Tempering on Hardness of C-Steels
KN5 C 0.14%
KN7 C 0.18%
KN12 C 0.28%
KN13 C 0.30%
KN14 C 0.32%
KN16 C 0.35%
Note: Bars of (18) were 28.6 mm diam.
836°Qo (111)
900°Qo (18)
870°Qw (18)
900°Qw (18)
870°Qo (18)
858°Qo (111)
866°Qo (111)
851°Qo (83)(103)
BHN
Tempering Temperature
°C

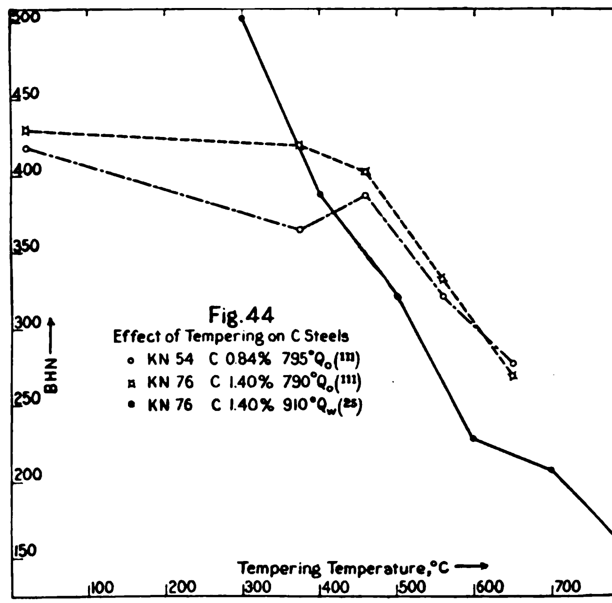


Fig. 44
Effect of Tempering on C Steels
KN 54 C 0.84% 795°Qo (111)
KN 76 C 1.40% 790°Qo (111)
KN 76 C 1.40% 910°Qw (25)
BHN
Tempering Temperature, °C

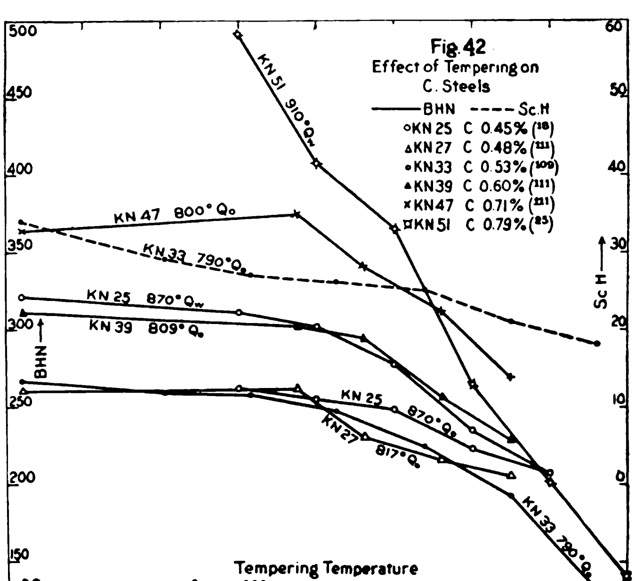


Fig. 42
Effect of Tempering on C. Steels
BHN ---- Sc.H
KN25 C 0.45% (18)
KN27 C 0.48% (111)
KN33 C 0.53% (109)
KN39 C 0.60% (111)
KN47 C 0.71% (111)
KN51 C 0.79% (83)
KN 51 910°Qw
KN 47 800°Qo
KN 33 790°Qo
KN 25 870°Qw
KN 39 809°Qo
KN 25 870°Qo
KN 27 817°Qo
BHN
Sc.H
Tempering Temperature
°C

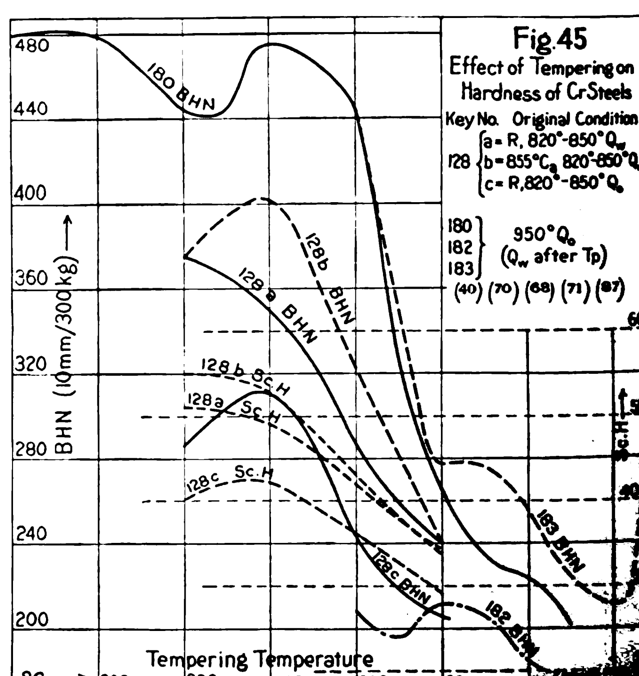


Fig. 45
Effect of Tempering on Hardness of Cr Steels
Key No. Original Condition
128 a = R, 820°-850°Qw
b = 855°Ca 820°-850°Qo
c = R, 820°-850°Qo
180, 182, 183 950°Qo (Qw after Tp)
(40) (70) (68) (71) (87)
180 BHN
128b BHN
128a BHN
128b Sc.H
128a Sc.H
128c Sc.H
128c BHN
183 BHN
182 BHN
BHN (10mm/300kg)
Sc.H
Tempering Temperature
°C

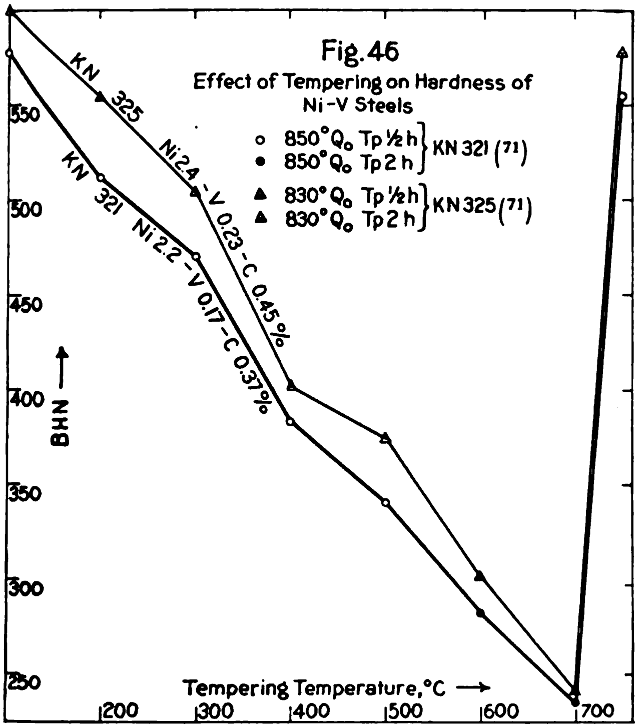


Fig. 46 Effect of Tempering on Hardness of Ni-V Steels

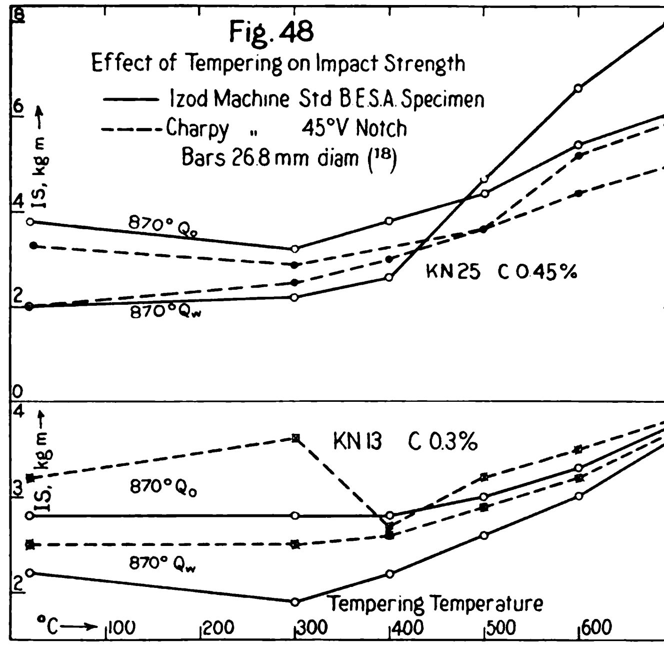


Fig. 48 Effect of Tempering on Impact Strength

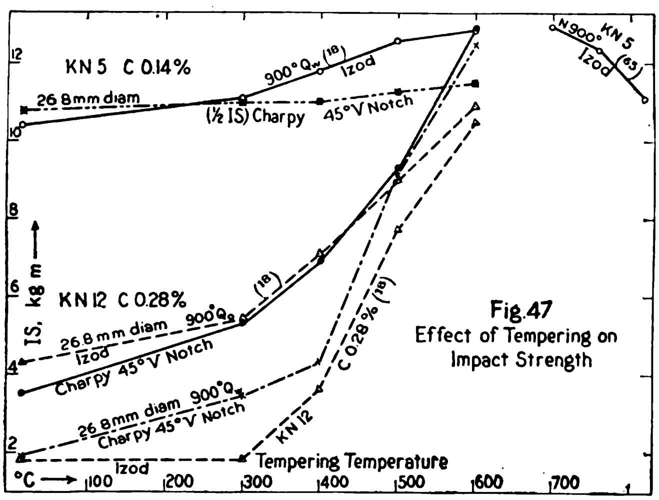


Fig. 47 Effect of Tempering on Impact Strength

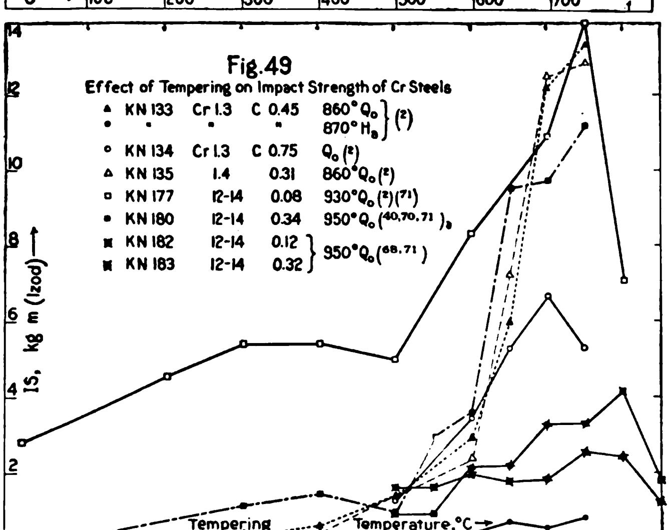


Fig. 49 Effect of Tempering on Impact Strength of Cr Steels

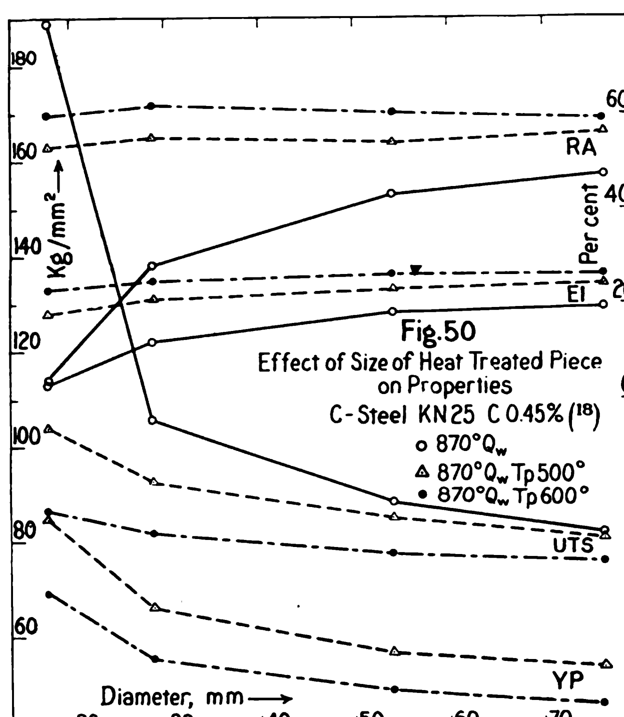


Fig. 50 Effect of Size of Heat Treated Piece on Properties C-Steel KN 25 C 0.45% (18)

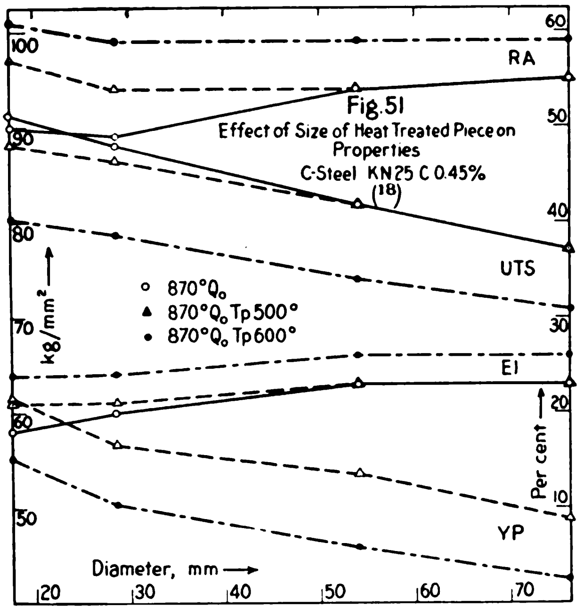


Fig. 51 Effect of Size of Heat Treated Piece on Properties C-Steel KN25 C 0.45% (18)

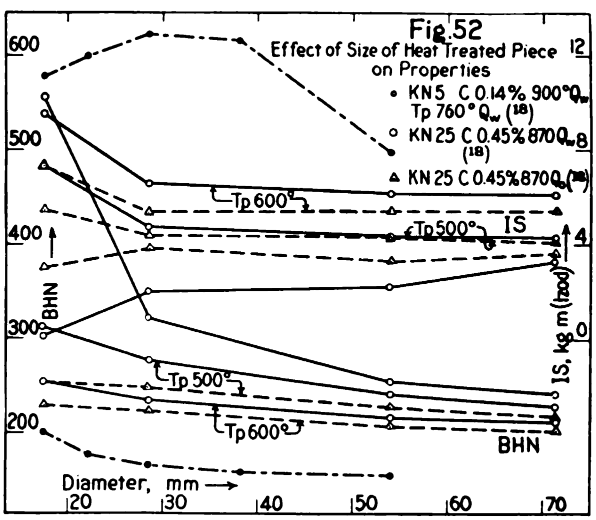


Fig. 52 Effect of Size of Heat Treated Piece on Properties

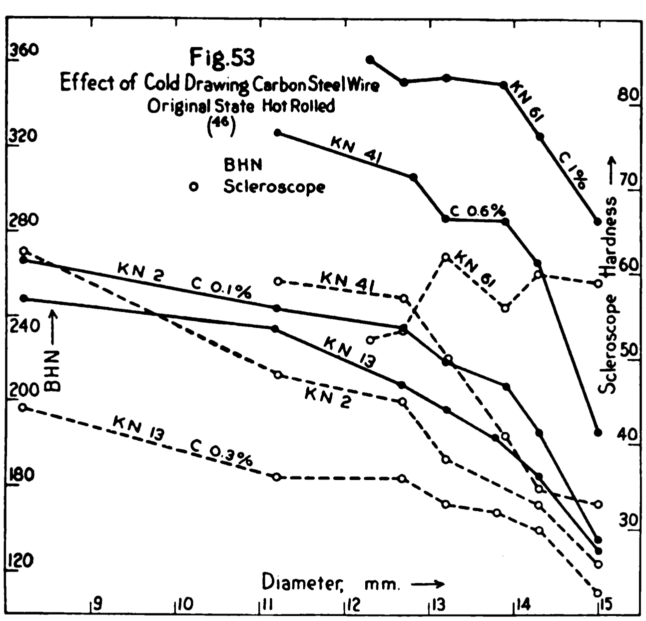


Fig. 53 Effect of Cold Drawing Carbon Steel Wire Original State Hot Rolled (46)

Table 4, Part I.—Cr Steels (Tensile, Hardness and Impact Tests)

For compression tests *v.* Fig. 40

Subscript $_o$ indicates rate of cooling through critical range

Key No.	Treatment*	*BHN*	*UTS*	*YP*	El_a	*RA*	*IS*†	Lit.
120	931 C_s 0.7$_c$°/m ...		52.1	28.6	31	47	IS_x‡	(108)
	I {700°} 60 C_a§	143	58.2	36.3	35	68	15.9	
	I {600°} 60 C_a§	161	64.6	47.6	31	64	13.2	
	II {735°/140 C_a§.	139	54.6	38.5	37	68	15.0	
	II {550°/20 Q_w...	184	67.8	50.3	28	57	7.5	
	1070° C_s 4$_o$°/m...	123	51.7	31.8	34	51	5.5	
121	A 790°..........	212	74.5	36.5	18.5	20.5		(111)
	790° Q_w..........	627	127.5					
	790° Q_o..........	418	141.6	86.2	3.5	6		
	Same, Tp {375°......	387	137.7	93.5	3.5			
	Same, Tp {460°......	430	138.4	97.7	2.5			
	Same, Tp {560°......	375	125.4	77.9	4			
	Same, Tp {650°......	321	112.1	67.1	11	13.3		
122	931° C_s 0.7$_c$°/m ..		56.0	33.4	31	47		(108)
	I {700°/60 C_a§...	165	63.0	42.4	35	68	12.3	
	I {600°/60 C_a....	178	67.1	45.3	31	64	10.3	
	II {735°/140 C_a§	152	59.0	41.8	37	68	12.5	
	II {550°/20 Q_w ..	194	69.4	49.8	28	57	7.7	
	1070° C_s 4$_c$°/m...	133	54.5	32.7	34	51	4.25	
123	*A* 800°/1.5 d C_f 3 d		68.0	32.2	24.5	40.5		(9)
124	C_a		109.1	*PL* = 79.1		16.5		(119)
125	C_a		35.4	*PL* = 22.5		75		(119)
126	931° C_s 0.7$_c$°/m...		53.6	33.9	33	53.5		(81, 79, 108)
	I {700°/60 C_a§...	167	60.8	45.0	32	70	19.0	
	I {600°/60 C_a....	180	65.8	49.0	27	65	16.2	
	II {735°/140 C_a§	157	58.3	40.7	34	69	20.0	
	II {550°/20 Q_w...	214	72.5	52.5	25	58	7.5	
	1070° C_s 4$_c$°/m...	126	52.7	31.0	34	53.5	6.25	
							IS_u	*PL*
	1000° Q_o Tp 650°/120 {Q_w	198	66.6	43.0	28	67	6.35	28.3
	1000° Q_o Tp 650°/120 {C_s	192	63.9	41.7	28	67	5.5	34.6
	900° Q_o Tp 650° {60 C_a	193	66.8	45.2	27	69	7.35	34.6
	900° Q_o Tp 650° {120 Q_w	194	64.1	42.3	30	70	7.35	31.5
	900° Q_o Tp 650° {120 C_s	192	63.5	42.3	30	70	6.8	34.6
	900° Q_o Tp {600°} 120 C_a	199	67.7	45.2	27	65	5.5	36.2
	900° Q_o Tp {550°} 120 C_a	215	71.6	50.2	24	59	4.7	42.5
	900° Q_o Tp {500°} 120 C_a	216	71.8	49.4	23	59	3.9	44.1
	820° Q_o Tp {650°} 120 C_a	185	63.6	41.4	31	70	6.65	36.2
	820° Q_o Tp {600°} 120 C_a	193					5.7	
	820° Q_o Tp {550°} 120 C_a	210	66.8	42.0	28	65	4.3	37.8
	820° Q_o Tp {500°} 120 C_a		70.6	46.4	25	62		39.4
127	A 850°/60 C_f.....	210	*ScH* = 32					(87)
	850° Q_o Tp {500°} 60	350	*ScH* = 54					
	850° Q_o Tp {275°} 60	515	*ScH* = 70				IS_x‡	
128	931° C_s 0.7$_c$°/m or *VI*..........	*125*	54.4	28.0	32	47	*6.5*	(87, 108)
	I {700°/60 C_a§...	167	63.6	48.8	31	69	16.4	
	I {600°/60 C_a....	196	70.5	55.3	27	66	13.1	
	III§ or *V*§........	*151*	61.7	47.8	33	70	*18.0*	
	IV§ or V_a§.......	*209*	74.9	57.9	26	63	*13.6*	*ScH*
	R (*v.* Figs. 34 and 45)........	174	67.6	40.7	24.5	54.5		[illegible]
	RW 815° C_a......	162	64.9	39.2	28	59.5		[illegible]
	RW 815° C_f......	146	57.1	32.7	26	50		[illegible]
130	*A* 800°/1.5 d C_f 3 d		68.2	29.6	22.5	39		[illegible]
131	C_a..............		132	*PL* = 132		7.5		[illegible]
132	C_a..............		56.5	*PL* = 43		58		[illegible]
133–135	*v.* Figs. 35, 36 and 49							
136	931° C_s 0.7$_c$°/m or *VI*§..........	*124*	54.4	28.0	32	47	[illegible]	[illegible]
	I {700°} 60 C_a§	189	63.6	48.8	31	69	[illegible]	
	I {600°} 60 C_a§	211	70.5	55.8	27	66	[illegible]	
	III or *V*§........	*163*	61.7	47.9	33	70	[illegible]	
	IV or V_a§.......	*240*	74.9	57.9	26	63	[illegible]	

TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(*Continued*)
For compression tests *v.* Fig. 40

Key No.	Treatment*	*BHN*	*UTS*	*YP*	El_a	*RA*	*IS*†	Lit.
136	900°/30 C_a	183					IS_u	*PL*
	1000°/Q_o Tp 650°/120 Q_w	210	71.3	53.8	25	64	8.2	37.8
	C_a	207	69.9	52.4	25	64	5.7	45.7
	900° Q_o T_p 650°/60 C_a	225‖	73.5	56.4	25	69	9.3	50.4
	650°/120 Q_w	205	69.9	52.7	26	69	9.1	40.9
	650°/120 C_a	200	67.7	51.5	25	69	8.6	45.7
	600°/120 C_a	229	78.7	60.5	23	65	7.6	52.0
	550°/120 C_a	257	84.2	68.1	21	58	5.0	58.3
	500°/360 C_a	255	84.3	67.7	20	57	3.5	59.8
	820° Q_o Tp 650° 120 C_a	198	67.2	49.4	26	70	9.3	44.1
	600°	223	73.8	57.0	23	64	7.5	48.8
	550°	244	81.4	64.3	21	61	4.4	56.7
137	As received	150						(105, 107)
	950° C_a	150	52.6	33.0				
	A 950° 35 h C_f	115	52.0	25.2				
	850° Q_w Tp 400° C_a	375	107.9	105.4				
	550°	305	91.4	86.6				
	700°	195	64.9	50.4				
138	As received	179						(11, 105, 107, 108)
	As received, *A* 805°	205	73.8		26.5			
	850°	195	71.1	39.4	26.5			
	960°	146	54.8	28.3	23.5		IS_x‡	
	931° C_s 0.7$_c$°/m or *VI*§	*139*	57.3	23.0	28	51	*4.5*	
	I 700° 60 C_a§	200	73.8	60.1	27	69	15.0	
	600°	248	88.1	76.6	22	62	12.0	
	III§ or *V*§	*170*	65.5	53.5	31	72	*17.5*	
	IV§ or V_a§	*253*	88.7	78.7	19	57	*11.0*	
	950° C_a	187	71.8	44.1	26	62.5		
	A 950°/35 h C_f	116	47.8	22.7	37	70.5		
	850° Q_w Tp 400° C_a	418	157.4	144.8	9.5	37		
	550°	347	125.4	119.4	15	52		
	700°	241	86.3	74.0	22.5	67		
139	As received	196						(105, 107)
	900° C_a	242	96.1	66.1	20	55.5		
	A 950°/35 h C_f	149	59.3	20.2	28	55.5		
	800° Q_w Tp 400° C_a	454	176.6	164.2	9	30		
	550°	382	141.1	133.9	13	42.5		
	700°		98.3	89.8	21	61.5		
140	As received	290						(105, 107)
	900° C_a	298	107.0	88.2	16	40		
	A 950°/35 h C_f	226	78.5	50.5	21.5	62		
	800° Q_w Tp 550° C_a	415	151.8	148.0	10	32.5		
	700°	265	98.4	89.4	21	56		
141	As received	319						(11, 105, 107, 108, 119)
	900° C_a	262	112.0	81.8	10	18		
	As received, *A* 805°	205	73.0	39.4	23			
	850°	200	70.3	42.0	31			
	960°	270	96.0	55.0	9			
	960° Q_o Tp. 600°		135.0		6			
	650°	477						
	A 950°/35 h C_f	205	63.2	29.6	32	63.5		
	800° Q_w Tp 550° C_a	402	150.6	145.6	8.5	28		
	700°		99.3	90.5	20	52		
142	FA ‖		77	33–56	18.5–20.5			(35)
	FA ⊥		63	30–53	13–21			
143	931° C_s 0.7$_c$°/m or *VI*§	*162*	67.0	29.8			4.0	(108)
	I 700° 60 C_a§	212	75.8	65.0			12.0	
	600°	270	100.2	85.5			9.2	
	III§ or *V*	*172*	66.1	56.0			16.5	
	IV§ or V_a	*300*	96.4	85.0			7.5	
							IS_u	*PL*
145	1000° Q_o Tp 650°/120 Q_w	253	84.7	69.4	25	67	8.15	48.8
	C_a	244	80.7	65.5	25	68	3.7	53.6

TABLE 4, PART I.—CR STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(*Continued*)
For compression tests *v.* Fig. 40

Key No.	Treatment*	*BHN*	*UTS*	*YP*	El_a	*RA*	IS_u	*PL*
145	900° Q_o T_p 690°/120 C_a	209	71.1	58.1	27	70	10.4	47.2
	650°/60 C_a	255	85.2	70.1	23	69	8.7	53.6
	650°/120 Q_w	246	80.8	63.8	25	70	9.0	39.4
	650°/120 C_a	236	77.9	61.2	25	70	4.55	48.8
	900° Q_o T_p 600°/120 C_a	296	97.6	81.7	20	61	3.3	64.5
	550°/120	342	116.0	102.0	16	56	1.8	77.2
	500°/360	391	130.7	119.3	14	47	0.7	93.0
	820° Q_o Tp 650° C_a	225	77.3	63.3	25	65	12.7	52.0
	600°	281	95.6	84.4	20	60	3.9	61.5
	550°	325	110.3	100.2	18	59		77.2
	700°		78.1	64.7	25	68	13.6	
	750°		69.3	59.0	29	71	15.4	
							IS_x‡	Lit.
	931° C_s 0.7$_c$°/m or *VI*§	*162*	67.3	29.2	24	45	*4.5*	(3, 51, 79, 108)
	I 700° or *V*§	*173*	71.5	63.5	27	67	*15.5*	
	600° or V_a§	*287*	101.2	80.9	18	57	*8.1*	
	I_a 700° 60C_a§	182	66.0	53.4	29	69	17.8	
	600°	252	81.5	68.9	19	58	5.9	
147	As received, *A* 850°	137	50.6	23.6	35			(11, 108)
	960°	163	61.1	29.9	26			
	960° Q_o Tp 610°/60		88.6		19			
	931° C_s 0.7$_c$°/m		55.2	26.1	32	67		
	I 700° 60 C_a§		65.9	53.5	29	72		
	600°		87.1	79.4	19	61.5		
	I_a 700°	191	65.4	51.4	28	72	17.4	
	600°	254	83.9	70.5	22	65	8.9	
	II 780°/120 C_a§	163	59.0	52.0	35	73.5	22.0	
	1070° C_s 4$_c$°/m	142	46.7	28.5	36	67	6.5	
148	931° C_s 0.7$_c$°/m or *VI*§	*166*	57.8	27.6	31	67	*4.5*	(108)
	I 700° 60 C_a§		70.7	57.8	26	66		
	600°		95.1	87.9	18	56		
	I_a 700°	186	70.3	56.5	26	66	16.2	
	600°	261	93.5	78.3	20	56	5.7	
	III§ or *V*	*176*	68.1	58.0	30	68	*15.0*	
	IV§ or V_a	*281*	94.8	85.0	18	55	*8.1*	
149	As received, *A* 805°	192	78	37	25			(11)
	850°	225	80	37.8	22			
	960°	228	84	42	15			
	960° Q_o Tp 650°		120		10			
	960° Q_o 500°/60 C, Tp_2 650°	311						
150	C_a		60.3	*PL* = 56.5		62		(119)
151	C_a		133.3	*PL* = 84.4		7.5	IS_u	(119)
152	850° Q_o Tp 700°		70.3	51.3	15	57	9.25	(2)
153	931° C_s 0.7$_c$°/m or *VI*	*165*	54.8	24.6	36	73	*5.1*	(108)
	I 700° 60 C_a		71.7	58.0	28	65	IS_x‡	
	600°		93.9	83.6	18	56		
	I_a 700° 60 C_a	190	71.8	55.9	25	66	14.0	
	600°	270	88.1	76.7	20	57	5.9	
	III_a§ or *V*	*180*	68.6	50.4	31	68.5	*15.1*	
	IV§ or V_a	*278*	100.8	89.4	18	55	*7.1*	
154	*A*		59.4	25.4	31.5	64		(9)
155	As received, *A* 805°	210	74.4	41.0	26			(11)
	850°	202	68.5	37.8	30.5			
	960°	228	82.9	41.0	19			
	960° Q_o Tp 650°/60		119.2		12.5			
	960° Q_o 500°/60 C Tp_2 650°		*BHN* = 340					
156	931° C_s 0.7$_c$°/m		52.8	21.3	34	67		(108)
	I 700° 60 C_a§		65 7	55.2	29	72		
	600°		87.1	79.2	21	63		
	I_a 700° 60 C_a§	187	66.4	54.2	28	71	18.7	
	600°	248	88.1	77.1	22	63	8.1	

Table 4, Part I.—Cr Steels (Tensile, Hardness and Impact Tests).—(*Continued*)

For compression tests *v.* Fig. 40

Key No.	Treatment*	*BHN*	*UTS*	*YP*	El_a	*RA*	IS_x‡	Lit.
156	II 780° 120 C_a§	154	56.6	45.2	36	74.5	23.5	
	II 740° 120 C_a§	173	60.1	45.2	30	73	19.2	
	II 550°/120 Q_w..	344	129.4	105.5	15	46	5.1	
	1070° C_s 4_c°/m...	135	53.6	25.2	34	63	1.5	
157	931° C_s 0.7_c°/m or VI_a§	*192*	59.7	31.1	32	69	*3.5*	(108)
	I 700° 60 C_a§		76.6	61.1	26	60.5		
	I 600° 60 C_a§		96.5	87.9	18	52		
	I_a 700° 60 C_a§	205	77.3	59.4	25	61.5	8.9	
	I_a 600° 60 C_a§	263	90.7	72.7	19	53.5	5.1	
	III§ or *V*.........	*203*	74.3	53.6	29	63	*10.2*	
	IV§ or V_a........	*287*	101.8	91.9	18	50	*5.05*	
158	931° C_s 0.7_c°/m...		51.7	23.4	36	70		(108)
	I 700° 60 C_a§		65.1	52.8	29	72		
	I 600° 60 C_a§		83.8	74.8	20	64		
	I_a 700° 60 C_a§	187	66.9	54.4	28	72	18.7	
	I_a 600° 60 C_a§	240	84.7	76.0	21	66	10.3	
	II 780° 120 C_s	158	58.0	42.6	34	73	20.7	
	II 740° 120 C_s	166	59.0	45.5	30	72	21.1	
	II 550°/20 Q_w...	348	130.0	94.0	14	46	5.05	
	1070° C_s 4_c°/m...	136	52.7	24.2	34	65	1.7	
159	850° Q_o Tp 500°		144.7	130.0	10	30.5	IS_u	(2, 11)
	850° Q_o Tp 600°		92.1	77.3	18	50	2.1	
	850° Q_o Tp 700°		76.6	55.5	23	60.5	10.4	
	As received, A 805°	200	69.1	59.8	25			
	As received, A 850°	160	57.6	25.2	34			
	As received, A 960°	170	63.3	33.0	25			
	960° Q_o Tp 650°..		95.0		17			
	960° Q_o 500°/60, Tp: 650°........	286						
160	820° Q_o Tp 650°..		103.3	93.7	15.5	54.5		(1)
	Same, tested at 700°		26.8					
	Same, tested at 900°		11.0					
161	As received, A 805°	223	78.2	42.5	32.5			(1, 11)
	As received, A 850°	210	74.3	37.8	26.5			
	As received, A 960°	202	70.0	37.8	26.5			
	820° Q_o Tp 650°..		122.4	114.2	11.5	28.5		
	Same, tested at 700°		29.0					
	Same, tested at 900°		11.80					
	960° Q_o Tp 650°..	350						
162	C_a...............		124.3	*PL* = 60		17.6		(119)
163	C_a...............		150.6	*PL* = 100		7.5		(119)
164	As received, A 805°	175	64.3	56.7	30			(11)
	As received, A 850°	174	62.1	33.0	32			
	As received, A 960°	177	69.0	31.5	23.5			
	960° Q_o 500°/60 Tp: 650°........	255						
165	As received, A 805°	223	83.1	53.5	18			(11)
	As received, A 850°	207	73.8	37.8	23.5			
	As received, A 960°	196	68.3	37.8	25			
166	C_a...............		143.0	*PL* = 130.0		4.5		(119)
167	C_a...............		94.1?	*PL* = 79		0	IS_u	(119)
168	875° Q_o Tp 500°		149.0	132.8	9	25		(2)
	875° Q_o Tp 600°		89.3	73.1	18	50	4.0	
	875° Q_o Tp 700°		72.4	52.7	22	57	11.4	
171	C_a...............		139.3	*PL* = 102		0		(119)
172	*A*...............		58.5	26.0	29	56.5		(9)
173	As received, A 805°	185	54.8	33.0	34.4			(11)
	As received, A 850°	190	52.4	25.1	32.0			
	As received, A 960°	200	50.9	28.4	28.9			
174	As received, A 805°	153	65.0	28.3	31			(11)
	As received, A 850°	143	67.2	31.5	27			
	As received, A 960°	140	67.1	37.8	26			

Table 4, Part I.—Cr Steels (Tensile, Hardness and Impact Tests).—(*Continued*)

For compression tests *v.* Fig. 40

Key No.	Treatment*	*BHN*	*UTS*	*YP*	El_a	*RA*	IS_u†	Lit.
175	900° H_a Tp 700°..		67.7	50.4	21	48	6.8¶	(1)
176	900° H_aTp 650°		93.5	72.4	19	41	1.65	(2)
	900° H_aTp 700°		83.6	70.3	21	56	2.8	
	900° H_aTp 750°		78.7	57.7	24	47	3.2	
177	A 1000°..........		48.8	26.8	40	74.5		(40, 71)
	A_c 950°..........	143		*v. also* Figs. 9,				
	A_c 850°..........	143		37, and 49			8.85	
	1000° Q_o 750°/6 h						13.85	
	C_f..............	165						
178	*v.* Fig. 25							
179	950° Q_o Tp 650° Q_w	217**	77.2	62.7††	22	55	6.65	(65, 71)
	950° Q_o Tp 250° Q_w	444‡‡	168.0	149.5	7	59.5	1.1	
180	*v.* Figs. 37, 45, 49							
181	As received, D_c...		80.1	61.4§§	21	50	‖‖	(2, 11, 122)
	A 805°..........	185	69.2	34.6	33			
	A 850°..........	190	66.8	33.0	30	*v. also* Figs.		
	A 960°..........	192	68.6	31.5	23	10 and 25		
182	*v.* Figs. 11, 38, 45, 49							
183	975° Q_o Tp 700°..	255	88.1	70.3¶¶	21.5	53.0	2.8	(65)
	v. also Figs. 11, 38, 45, 49							
							IS_v¶	
184	900° H_a Tp 700°..		91.6	64.3	15.5	30.5	1.0	(1)
	Same, tested at 700°		20.8				2.5	
	Same, tested at 800°		12.4				3.5	
	Same, tested at 900°		11.8				5.0	
	Same, tested at 1000°		6.0				6.1	
186	*A*..............		69.2	32.8	20	36	IS_u	(9)
187	875° Q_o Tp 500°		132.9	106.2	4	5		(2)
	875° Q_o Tp 600°		92.8	69.6	13.5	37.5	5.1	
	875° Q_o Tp 700°		71.0	45.7	20	40.5	9.7	
	875° Q_o Tp 750°		74.5	49.9	23	50	8.0	
188	*A*..............		89.5	76.7	16	26.5		(9)
190	*A*..............		77.3	54.8	12.0	21.5		(9)
191	As cast..........		28–63	21–56	2–0	3–0		(34)
	R or F..........		56–91	46–78	26–8	50–10		

* Italicized numerical values are for the alternative treatments (as indicated by footnote§).

† For meaning of subscripts *v.* p. 396.

‡ Tested on the Guillery machine.

§ Meanings of treatments denoted by Roman numerals are: I = 950°/30 C_a 860°/30 Q_o Tp; I_a = 950°/30 C_a 870°/30 C_a Tp; II = 1065°/30 C_a 850°/60 Q_o Tp; III = 950°/60 C_a, 825°/30 Q_o 735°/255 C_a 630°/120 C_a; III_a = 915°/60 C_a 820°/30 Q_o 750°/255 C_a, 620°/140 C_a; IV = 950°/60 C_a 825°/30 Q_o 625°/30 C_a; V = 1000°/20 C_a, 830°/30 Q_o 745°/60 C_a; V_a = 1000°/20 C_a 830°/30 Q_o 600°/20 Q_w; VI = 1020° C_s 2_c°/m; VI_a = 1070° C_s 4_c°/m.

‖ *ScH* = 41.

¶ Charpy machine, type of specimen not stated.

** *ScH* = 35.

†† *PL* = 47.2.

‡‡ *ScH* = 64.

§§ *PL* = 14.2 on 2 in., 11.0 on 8 in., *EL* = 11.0 on 8 in.

¶¶ *PL* = 53.2.

‖‖ 900° H_o Tp 500°, IS_u = 1.1.
900° H_o Tp 600°, IS_u = 2.1.
900° H_o Tp 700°, IS_u = 4.15.

Table 4, Part II.—Shear and Torsion Tests on Cr Steels

Tests on air cooled specimens on Fremont shear machine (119)

Key No.........	124	131	132	141	144	151	162	163	167	171
USS..........	49	57	19	56	36.5	56	40	51.5	39.5	67.5

Table 4, Part II.—Shear and Torsion Tests on Cr Steels.—(*Continued*)

Torsion tests

Key No.	Treatment	USS_C*	TMR†	YP_S	PL_S	Tw, °/cm	Lit.
127‡	A 850°/60 C_f....	48	65		29	33.8	(87)
	850° Q_o {500°/60	70.5	94		72	17.7	
	Tp {275°/60	103.5	138		90	4.7	
128‡	A 850°/60 C_f....	44	58.5		25	50.4	(87)
	850° {515°} 60	61.5	82		63.5	26.4	
	Q_w {570°} 60	59	79		57	28.7	
	Tp {620°} 60	56.5	75.5		54	39.4	
179§	950° {650° Q_w	52	69	41		107.5	(65)
	Q_o Tp {250° Q_w	90	120	79.5		15.3	

* Stress assumed uniform throughout cross-section.
† TMR = 1.333 USS_C.
‡ Size of specimen unknown.
§ Specimen 1¾ in. × ⅝ in. diam.

Table 5.—Cr-V Steels

See also Figs. 12, 26, 28, and 39

Key No.	Treatment	BHN	ScH	UTS	YP	El_a*	RA	Lit.
192	As rolled.........			43.5	34.3	38	63	(126)
194	As rolled.........			56.7	37.0	28	45	(126)
	A 620°...........			56.1	35.9	30.5	55.5	
195	As received.......	302	42	96.1	59.9	15.5	45.5	(53)
	927° Q_o 870° Q_o Tp 650°.........	300	48	101.8	94.9	18	62	
196	As rolled.........			76.5	57.0	24	56.5	(126)
	A 650°/30........			79.1	60.2	23	56.4	
	A 850°/30........			61.1	44.1	26	65	
198	A 800-900°			114.2	71.7	9	44	(126)
	Q_o Tp...........			126.5	84.9	12.5	46	
199	S 1200°/12h {750°			65.4	42.5	23	38	(126)
	C_m W_2 {950°			88.7	59.2		49.5	
	500° Q_o Tp 350°..			84.6	61.3	26	51	
	690° Q_o Tp 350°..			82.8	59.8	26	51	
	690° Q_o Tp 600°..			83.5	60.3	25	50	
	870° Q_o Tp 350°..			93.5	78.4	23	51	
	900° Q_o Tp 600°..			84.5	68.4	22	56.5	
	1000° Q_o Tp 350°.			92.1	79.5	20	37.5	
200	As rolled.........			104.2	66.9	16.5	40.5	(126)
	A 800°/30........			83.6	61.9	23.5	52	
201	850° Q_o Tp 650°..			93.5	70.9	18	50	(71)
202	850° Q_o Tp 420°..	444	63	169.0	140.9	8.5	24	(65)
203	850° Q_o Tp 650° C_a	255	41	89.0	76.5†	22	60.5	(65)

From torsion tests: No. 193 {(As received): USS_C = 72.5, TMR = 97; (A): USS_C = 51.5, TMR = 69} (16).

No. 203, (850° Q_o Tp 650° C_a): USS_C = 61.5, TMR = 82, YP_S = 58, Total Tw = 532° (65).

Impact strength: No. 202, IS(Izod) = 1.9, IS_w = 0.8; No. 203, IS(Izod) = 4.8 (65).

* For key Nos. 192, 194, 196, 199, 200 specimens are 2 in. × 0.75 in. diam. and for key No. 198 specimens are 2 in. × 0.375 in. diam.
† PL = 60.8.

Table 6.—Copper Steels

Cold drawn copper steels (133, 134, 143)

Key No.	Treatment	Diam. mm	UTS	El
204	D_o......................	4.37	129.1	5_k
	D_o......................	3.23	158.0	5.5_k
	D_o......................	2.34	194.5	5_k
207	A......................	(5 SWG)	83.8	18_k
	D_o......................	3.25	69.5	
	D_o......................	1.93	93.5	
210	D_o......................	5.59	128.0	5_k
	D_o......................	2.95	165.4	4.5
	D_o......................	1.83	207.6	3.5

Table 6.—Copper Steels.—(*Continued*)

Key No.	Treatment	Diam. mm	UTS	El
212	A......................	(5 SWG)	74.8	15_k
	D_o......................	3.25	66.6	
	D_o......................	1.85	112.2	
213	D_o 4 SWG..............	5.21	93.7	3.5_k
	D_o......................	2.92	141.9	3
	D_o......................	1.30	205.4	2
216	AC > 24 h..............	(5 SWG)	64.9	11
	D_c......................	4.70	86.4	2
	D_o......................	3.81	99.2	3
	D_o......................	3.07	113.5	2.5
	A_2 D_o..................	2.77	75.9	3
	D_o......................	2.13	91.4	2
	D_o......................	1.83	103.9	3.5
	A_2 D_o..................	1.65	67.8	2
	D_c......................	1.02	98.4	1.5
218	AC > 24 h..............	(5 SWG)	89.9	8
	D_o......................	4.70	114.2	3
	D_o......................	3.81	128.2	3
	D_o......................	3.07	151.3	4
	A_2 D_o..................	2.77	91.4	3.5
	D_o......................	2.13	111.5	2.5
	A_2 D_o..................	1.83	125.2	3
	A_2 D_o..................	1.42	146.8	3
	A_2 D_o..................	0.99	154.4	2
221	A......................	5.44	86.1	15_k
	D_o......................	3.25	71.7	
	D_o......................	1.85	105.5	
224	AC > 24 h..............	(5 SWG)	64.5	14
	D_o......................	4.70	86.0	3
	D_o......................	3.81	100.0	3
	D_o......................	3.07	107.3	4
	A_2 D_o..................	2.77	81.3	3
	D_o......................	2.13	101.7	2
	D_o......................	1.83	104.7	3
	A_2 D_o..................	1.65	72.7	2
227	A......................	5.49	92.1	12.5_k
	D_o......................	3.25	66.7	
	D_o......................	1.88	100.8	
233	AC > 24 h..............	(5 SWG)	65.5	12
	D_o......................	4.70	82.4	2
	D_o......................	3.81	94.5	3
	D_o......................	3.07	103.1	3.5
	A_2 D_o..................	2.77	88.2	2.5
	D_o......................	2.13	105.8	2.5
	D_o......................	1.83	107.3	2.5
	A_2 D_c..................	1.65	76.0	2
	A_2 D_c..................	1.02	106.6	1.5

Cast, rolled and forged copper steels

Key No.	Treatment	Diam.*	BHN†	UTS	YP	El‡	RA	Torsion data§	Lit.
205	As cast............	A		36.8	18.3	24_d	53	Specimens 100 mm × 18 mm diam. (as rolled)	(82)
	A 800°............	A		37.4	17.9	22_d	59.5		
	A 1000°...........	A		39.0	24.7	28_d	67		
	A 1200°...........	A		38.1	20.2	28.5_d	64		
206	F................	B		60.0		13_d	48.5		(17)
	CR Q_w Tp *DR*......	B		103.0		16_d	45		
	CR Q_o Tp *DR*......	B		82.5		23_d	48.5		
208	R................	D	120	39.2	28.4	25_f	42		(82)
209	G.......	A	170	61.2	31.5	17_d	20		(82)

TABLE 6.—COPPER STEELS.—(*Continued*)
Cast, rolled and forged copper steels

Key No.	Treatment	Diam.*	BHN†	UTS	YP	El‡	RA	Torsion data§	Lit.
211	F	B		62.0		23_d	48.5		(17)
	Q_w Tp	B		97.9		10.5_d	58		
	Q_o Tp	B		75.7		15_d	56		
214	R	B	146	47.1	38.7	25.5_d	66	$USS_C = 39.5$	(17)
	A 900°	B	143	41.5	26.9	28_d	60	$TMR = 52.5$	
	870° Q	B	311	67.0	49.7	16_d	53	$YP_S = 31$	
	Same, Tp 300–350°	B	311	72.2	51.2	8.5_d	60	$Tw = 77$	
215	R	B	202	65.5	48.6	20_d	48.5	$USS_C = 43$	(17)
	A 900°	B	166	54.7	33.4	23.5_d	43	$TMR = 57.5$	
	870° Q	B	627	76.5	76.5	1.5_d		$YP_S = 33$	
	Same, Tp 300°	B	460	139.0	135.1	1.5_d		$Tw = 19.6$	
216	R			73.3	39.4	19	20.5		(133)
217	R	B	255	83.5	62.1	12_d	22.5	$USS_C = 68.5$	(17)
	A 830°	B	228	72.3	41.1	16.5_d	43	$TMR = 91.5$	
	830° Q_w	B	817					$YP_S = 54.5$	
	Same, T_p 300–350°	B	555	158.0	158.0	0_d	0	$Tw = 27.2$	
219	R‖	B	286	102.8	71.7	5.5_d	4	$USS_C = 76.5$	(17)
								$TMR = 102$	
	W_2 825° C	B	235	79.4	48.0	16_d	34	$YP_S = 51$	
	825° Q_h	B	332	108.0	76.0	8_d	27	$Tw = 13$	
220	F	B		66.3		20_d	55		(17)
	CR Q_w Tp *DR*	B		103.8		11_d	57		
	CR Q_o Tp *DR*	B		83.6		15_d	55		
222	F	B		68.2		17.5_d	61		(17)
	CR Q_w Tp *DR*	B		112.2		9_d	66		
	CR Q_o Tp *DR*	B		81.5		13_d	62		
223	As cast			28.8		10_b			(12)
225	R	B	146	49.5	41.5	26.5_d	60	$USS_C = 41.5$	(17)
	A 900°	B	146	49.0	38.6	26_d	57	$TMR = 55$	
	870° Q	B	311	92.8	83.3	5.5_d	26	$YP = 29$	
	Same, Tp 300°	B	277	69.0	52.9	11.5_d	66	$Tw = 92.5$	
226	R	B	207	64.5	45.2	20.5_d	47	$USS_C = 48$	(17)
	A 900°	B	196	60.6	40.9	20_d	40	$TMR = 64$	
	870° Q	B	600	102.5	102.5	1.5_d		$YP_S = 40.5$	
	Same, Tp 300°	B	495	166.5	149.0	3.5_d	7.5	$Tw = 44.6$	
227	R	B	418	96.0	55.3	12.5_d	17	$USS_C = 71$	(17)
	A 830°	B	223	75.5	42.4	8.5_d	18	$TMR = 94.5$	
	830° Q		800					$YP_S = 59$	
	Same, Tp 350°		600					$Tw = 24.8$	
228	R	B	364	110.0	69.3	6_d	7	$USS_C = 69$	(17)
								$TMR = 92$	
	A 825°	B	277	80.0	56.5	16.5_d	32	$YP_S = 54.5$	
	825° Q_h	B	311	92.5	70.0	8_d	31	$Tw = 10.8$	
229	R			66.4	44.1	23	35		(134)
231	1000° C_a	C		34.8	30.8	30.5_a	62		(6)
232	R	B	202	62.5	47.4	16_d	58.5	$USS_C = 47$	(17)
	A 900°	B	174	49.5	41.3	25_d	58	$TMR = 62.5$	
	870° Q	B	311	112.0	106.0	5_d	25.5	$YP_S = 44$	
	Same, Tp 300°	B		111.0	102.4	6.5_d	34	$Tw = 70.2$	
233	R			78.2	56.5	21.5	35		(134)
	A			74.3		20	36		
234	R	B	269	79.6	68.5	11_d	31.5	$USS_C = 55.5$	(17)
	A 900°	B	207	61.5	45.6	18_d	40	$TMR = 74$	
	870° Q	B	800	75.0	75.0	1_d		$YP_S = 49$	
	Same, Tp 300°	B	495	167.0	155.0	2_d	1.5	$Tw = 29.6$	
235	As cast			57.6		5_b			(12)
238	R	B	375	117.0	97.5	1.5_d	1.0	$USS_C = 74$	(17)
								$TMR = 98.5$	
	W_2 825° C	B	277	84.0	63.7	14_d	43	$YP_S = 66.5$	
	825° Q_h	B	311	107.5	86.9	4_d	17	$Tw = 16.2$	
240	As cast			72.0		5_b			(12)
241	R	B	255	77.1	69.5	13_d	46.5	$USS_C = 58$	(17)
	A 900°	B	183	50.3	46.0	22_d	63	$TMR = 77.5$	
	870° Q	B	351	137.9	106.0	7_d	29.5	$YP_S = 61.5$	
	Same, Tp 300°	B	325	100.0	85.5	11_d	52	$Tw = 18.3$	
242	R	B	302	97.1	81.8	11_d	23.5	$USS_C = 68.5$	(17)
	A 900°	B	212	68.5	56.5	16_d	42	$TMR = 91.5$	
	870° Q	B	782	100.2	100.2	1_d		$YP_S = 65$	
	Same, Tp 300°	B	782	173.0	157.9	1.5_d	1.0	$Tw = 18.3$	

* Diameters of tensile specimens: A = 10 mm, B = 13.8 mm, C = 14.33 mm, D = 20 mm.

† 10 mm ball, 3000 kg load.
‡ a = 2 in., d = 100 mm, f = 200 mm, k = 20 in., b = 1 in.
§ $TMR = 1.333\ USS_C$.
‖ Broke near head.

COMPRESSION TEST ON CYLINDER 28.47 × 14.33 MM DIAM. (1000° C_a)

Key No.	Compressive stress kg/mm²	31.5	63	94.5	126	157.5	Lit.
231	% compression	1.5	8	22		38.5	49.5	(6)

TABLE 7, PART I.—NICKEL CHROMIUM STEELS* (TENSILE, HARDNESS AND IMPACT TESTS)

Key No.	Treatment	BHN	UTS	YP	El	RA	IS_u†	IS_v†	Lit.
243	R_h		46	26‡	37.5	61.5			(128)
244	As received	255§	85.5	76.5	13	56			(71)
245	850° C_a	174	63	45.5	33	65	10.3	11.6	(18)
	850° Q_w Tp, 500° Q_w	302	101	88	18	58	6.9	8.1	
	850° Q_w Tp, 600° Q_w	255	80	71	25	66	11.6	13.3	
	850° Q_w Tp, 650° Q_w	229	74	63	27	69	12.9	15.0	
	850° Q_o	302	101	71	16	34	2.4	2.3	
	Same, Tp 300° Q_w	302	97.5	69	16	47	3.2	3.0	
	Same, Tp 400° Q_w	291	94.5	67	17	54	4.4	4.8	
	Same, Tp 500° Q_w	262	85	69	21	62	9.7	10.0	
	Same, Tp 600° Q_w	223	72.4	58	27	68	12.5	14.0	
	Same, Tp 650° Q_w	212					12.9	15.5	
	Same, Tp 700° Q_w		69	55	29	70			
246	850° C_a‖	444	157	110	12	38	0.7	0.9	(18)
	850° Q_w Tp‖, 500° Q_w	410	134	116.5	12	39	0.7	1.1	
	850° Q_w Tp‖, 600° Q_w	340	110	102.5	17	45	1.1	1.3	
	850° Q_w Tp‖, 650° Q_w	311	101	90	18	50	5.0	3.9	
	850° Q_o‖	532	204.5		2	5	0.55	0.8	
	Same, Tp‖ 300° Q_w	477	181	128	11	36	0.4	.7	
	Same, Tp‖ 400° Q_w	444	162	135	11	36	.3	.6	
	Same, Tp‖ 500° Q_w	401	137	124.5	12	39	.4	.9	
	Same, Tp‖ 600° Q_w	321	112	101	17	47	1.0	1.6	
	Same, Tp‖ 650° Q_w	293	102	91	20	52	5.4	5.3	
	850° Q_o	512	192	183	5	8	0.55		
	Same, Tp 500°	364	129	115	13	40	0.4		
	Same, Tp 650° Q_w	255	89.5	72.5	23	59	5.65		

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS_u†	Lit.
247	1000° Q_o Tp 650°/120 Q_w	241	80.5	63	50.5	21	51	7.05	(80)
	1000° Q_o Tp 650°/120 C_s	234	79.5	63	55	20	46	8.3	
	900° Q_o Tp 675°/120 C_a	238	80	63.5	53.5	21	45	6.8	
	900° Q_o Tp 650°/120 Q_w	245	82	67.5	53.5	19	46	6.8	
	900° Q_o Tp 650°/120 C_s	242	81	65	58	19	46	1.0	
	900° Q_o Tp 650°/360 C_a**	227	76.5	60	52	21	45	7.2	
	900° Q_o Tp 600°/120 C_a	270	91	77	63	18	39	4.85	
	900° Q_o Tp 550°/120 C_a	300	99.5	86.5	69	14	39	1.95	
	820° Q_o Tp 650°/120 C_a	244	81	65	58	21	47	6.8	
	820° Q_o Tp 600°/120 C_a	270	90	75.5	63	18	41	4.7	
	820° Q_o Tp 550°/120 C_a	301	100	86.5	71	15	37	1.95	
	FA, 850° Q_o Tp 660° C_a	224	75.5	56	49	20	51	4.3	
								IS_w‡‡	
248	A 900°/90 C_f	*v. also*	46	28		30.5	59	61.0	(89)
	Same, 870° Q_o 760° /60 Q_o 260°/60 C_a	Fig. 21	57.3	35.5		21	67	95.0	
249	A 900°/90 C_f	*v. also*	62.5	30		21	41	13.6	(89)
	Same, 825° Q_o Tp 600°/60 C_f	Fig. 22	86.2	71		20	58	34.2	
								IS_u	
250	1000° Q_o Tp 650°/120 Q_w	262	89	72.5	58	21	50	7.75	(80)
	1000° Q_o Tp 650°/120 C_s	257	87.5	70.5	63	21	50	0.4	
	900° Q_o Tp 675°/120 C_a	243	84	69	63	22	55	7.35	
	900° Q_o Tp 650°/120 Q_w	258	87.5	72.5	58	20	50	7.9	
	900° Q_o Tp 650°/120 C_s**	252	84.5	70	66	20	50	0.55	
	900° Q_o Tp 650°/360 C_a	236	80	65.5	61.5	22	47	7.9	
	900° Q_o Tp 600°/120 C_a	289	96.5	83.5	72.5	17	49	2.35	
	900° Q_o Tp 550°/120 C_a	325	109	97	86.5	13	39	0.7	

TABLE 7, PART I.—NICKEL CHROMIUM STEELS* (TENSILE, HARDNESS AND IMPACT TESTS).—(*Continued*)

Key No.	Treatment	*BHN*	*UTS*	*YP*	*PL*	*El*	*RA*	IS_u†	Lit.
250	820° 650°	255	85	73.5	69	22	54	7.2	
	Q_o 600° 120 C_a	296	96.5	84.5	74	18	47	2.6	
	Tp 550°	323	108	97	86.5	9	23	1.0	
	900° C_a 650°/2 h Q_w	248	83	64	50.5	21	56	8.15	
251	1000° Q_o Tp Q_w...	263	89	72.5	56.5	18	43	6.2	(80)
	650°/120 C_s ...	255	87	71	64.5	15	37	0.3	
	900° Q Tp 675°/120 C_a	243	83.5	69	64.5	13	37	5.1	
	650°/120 Q_w	258	87	71	57	20	50	6.4	
	650°/120 C_s **	250	84	71	66	6	15	0.4	
	650°/360 C_a	236	80	66.5	63	20	40	6.4	
	600°/120 C_a	304	102	88	77	10	19	1.0	
	550°/120 C_a	342	115.5	103	88	5	9	0.4	
	820° 650°	255	84.5	73	68	20	46	5.4	
	Q_o 600° 120 C_a	300	100	87	80	10	25	1.1	
	Tp 550°	338	114	103	91	6	19	0.7	
	F A 900°, 850° Q_o Tp 660° C_a............	235	79	65	62	20	47	1.95	
252	1200° Q_o Tp Q_w ...	228	75.5	59.5	41	19	43	6.5	(81, 80)
	650°/120 C_s ...	216	72.5	56	44	20	43	8.3	
	1000° Q_o Tp Q_w...	200	64	46	31.5	24	63	7.6	
	650°/120 C_s ...	195	63.5	47.5	36	23	63	3.05	
	900° Q_o Tp 650°/120 Q_w..	205	67	49	38	24	65	8.3	
	650°/120 C_s**	197	65	48.5	39.5	24	65	4.4	
	675°/120 C_a..	225	76.5	60.5	50.5	19	39	6.1	
	650°/360 C_a**	221	72.5	55	49	22	55	6.8	
	600°/120 C_a..	256	84	70	55	17	42	3.6	
	F A 815°, 805° Q_o Tp 625° C_a		69	52.5	42.5	20	49	3.75	
	680° C_a		62.5	45	36	24	56	5.65	
253	900° Q_o Tp Q_w....	250	83	66	53	21.5	55	4.9	(81)
	650°/120 C_s	245	81.5	64.5	53.5	21	51	0.6	
	1000° Q_o Tp Q_w...	259	85	68.5	53.5	20	49	4.6	
	650°/120 Cs ...	250	82	66	35	20	51	0.6	
	1200° Q_o Tp Q_w...	265						4.2	
	650°/120 C_f ...	258						0.4	
					IS_v†				
254	820° C_a............	163††	56.5	33	12.3	32	65	11.8	(18, 62)
	820° Q_o............	262	88	60?	6.3	20	53	5.8	
	Same, Tp 300° Q_w	255	85	60?	7.2	20	60	6.9	
	400°	241	80	61.5	9.5	21	63	8.3	
	500°	223	72.5	56.5	13.0	24	67	10.25	
	600°	192	64.5	50.5	15.0	28	71	13.0	
	650°	179	60	45.5	17.3	31	72	14.1	
					PL				
255	1200° Q_o Tp Q_w....	208	70.5	52	34	19	47	6.35	(80)
	650°/120 C_s**..	199	68.5	52	39	21	45	5.25	
	900° Q_o Tp Q_w	227	74	51	36	22	51	6.35	
	650°/120 C_s**...	219	71	53	44	23	51	5.8	
	F 815° Q_o Tp 650° C_a		66.5	39.5	31.5	22	44		
	F A 815°, 815° Q_o Tp 650° C_a............							4.4	
256	v. Fig. 13								
257	825° Q_o Tp 600° Q_w	286	102	95.5		18.5	54	9.4	(28)
	650°	269	93	77.5		22	61	11.1	
	845° Q_o Tp 600° Q_w	311	106.5	100		16.5	55	8.6	
	650°	262	91.5	79		23	61.5	10.5	
258	1000° Q_o Tp Q_w...	253	84.5	67	55	19	43	5.55	(80)
	650°/120 C_s**..	247	83.5	67	61.5	17	34	0.3	
	900° Q_o Tp 675°/120 C_a...	240	78.5	60	49	10	15	5.25	
	650°/120 Q_w...	253	84.5	67.5	56.5	18	45	5.95	
	650°/120 C_s**.	249	84	67.5	63	10	14	0.3	
	650°/360 C_a...	239	82	65.5	61.5	19	46	4.85	
	600°/120 C_a...	280	94	80	69.5	13	26	0.8	
	550°/120 C_a...	313	104.5	93	82	13	38	0.55	
	850° Q_o 660°/2 h C_a..		80	63	55	19	42		
	880° Q_o Tp 2 h 650° C_a	258	86.5	72	67.5	18	41	5.4	
	600°	280	94.5	83	72.5	13	24	1.0	
	550°	314	105	94.5	85	14	37	0.55	
	F A 900°, 850° Q_o, Tp 660° C_a............	237						1.95	

TABLE 7, PART I.—NICKEL CHROMIUM STEELS* (TENSILE, HARDNESS AND IMPACT TESTS).—(*Continued*)

Key No.	Treatment	*BHN*	*UTS*	*YP*	*PL*	*El*	*RA*	IS_u†	Lit.
259	As received..........		147.5	137		9.5	30.5		(71)
	950° C_a.............		141	125		11	31		
	A 950°...............		67.5	33		27	53		
	850° Q_o Tp 250°...		177	170		11	43.5		
	300°...		172	166		10	39		
	350°...		162.5	148		11	41		
260	F 900° Q_o Tp Q_w...	297	96.5	76	55	17	37	4.85	(51)
	650°/120 C_s ...	282	93.1	75.5	66	15	31	2.9	
261	F 900° Q_o Tp Q_w...	209	67.5	52.5	36	21	56	5.7	(51)
	650°/120 C_s ...	200	65	51	42.5	21	55	5.4	
262a	850° C_a.............	321	113	86.5		15	41	0.8	(4, 18, 47, 50, 51, 80, 109, 110)
b	N 820°..............	321	113	86.5	For other values of *IS* v. footnotes.‡‡‡‡	15	41	0.8	
c	Same, Tp 200° Q_w	321	111.5	88		15	46	1.1	
d	300°	321	111	95.5		15	48	0.4	
e	400°	302	105.5	89.5		16	51	0.7	
f	500°	277	94.5	80		18	54	2.35	
g	600°	255	85	71		22	60	6.65	
h	650°	241	82	67.5		23	62	8.85	
i	790° C_s**..	167****	61.5	42	40	33	67	6.9	
j	1000° Q_o Tp Q_w...	240	79	58.5	44	19	40	9.15	
k	670°/120 C_s ...	230	77	58	42.5	19	39	2.8	
l	1000° Q_o Tp Q_w...	245	78	61	45.5	23	55	7.6	
m	650°/120 C_a ...	245	78	62.5	49	25	58	4.15	
n	C_s**..	237	77	61.5	50	20	47	0.7	
o	(l) Tp_2 650° C_s**.....	235	75	59	49	22.5	52	0.7	
p	(n) Tp_2 650° Q_w.....	235	74	57	42.5	20	45	9.0	
q	900° Q_o 675°/2 h C_a	234	80	53	41	17	34	5.7	
r	900° Q_o Tp Q_w ...	245	81	64	46	21	54	6.1	
s	650°/120 C_s** ..	240	80	63.5	53	23	58	1.1	
t	(r) Tp_2 670° Q_w......	226	77	53.5	31.5	16.5	32	6.25	
u	900° Q_o 650°/6 h C_a..	226	76	60	47	20	43	6.4	
v	900° Q_o 600°/2 h C_a..	264	88	76	63	18	42	1.8	
w	900° Q_o 550°/2 h C_a..	286	94	84.5	69	15	37	1.0	
x	850° Q_o Tp Q_w ..	245	76.5	61	49	21	56	8.3	
y	650° C_s**..	240	76	60.5	52	22.5	56	1.25	
z	850° Q_w Tp Q_w ..	230	73	49	30.5	24	48	9.0	
aa	675°/495 C_s**..	220	71	48	33	25	52	5.1	
bb	820° Q_o Tp 2 h 400° Q_w	388	135	122.5		14	50	0.8	
cc	500° Q_w	331	115	105.5		18	54	2.8	
dd	550° C_a	287	94	85	69.5	4	7	1.1	
ee	600° Q_w	285	97.5	89	81§§	20	61	6.5	
ff	600° C_a	270	88	77	64.5	12	25	1.9	
gg	650° C_a	243	80.5	67.5	56.5	18	43	5.7	
hh	650° C_s**	224	74	60	47	16	32	1.8	
ii	(hh) Tp_2 650° Q_o.....	218	72	57.5	47	19	49	5.95	
jj	820° Q_o 705°, 75 C_a 600° Q_w	220	75	53.5	31.5	21	50	5.1	
kk	C_s**	217	74	50	31.5	21	43	2.2	
ll	820° Q_o 705°, 75 Q_o 600° Q_w	223	76.5	58	39.5	21	51	5.7	
mm	C_s**	214	73.5	54.5	42.5	19	45	2.35	
nn	820° Q_o 788° Q_o, Tp_2 650° C_s	247	79.5	73	71.5‖‖	24	69		
oo	Q_w	246	80	70.5	60.5¶¶	23	69		
pp	820° Q_o 788 C_s**....		61.5	42	40	33	67		
			v. *also* Fig. 13						
263a	1000° C_s 0.3$_c$°/m	229	78.5	45	30	22	51	2.8	(18, 28, 47, 50, 51, 65, 69, 71, 80, 109, 110)
b	800°	209	72.5	41.5	34.5	27	61	5.8	
c	1000° C_a............	296	99.5	63.5	16	16	41	1.8	
d	900° C_a Tp Q_w...	220	74	55.5	41	25	66	9.4	
e	650°/120 C_a...	217	73.5	56	45.5	25	66	9.4	
f	800° C_a.............	296	100	64	20.5	18	43	2.35	
g	1000° Q_o Tp Q_w...	267	90	50.5	23.5	19	47	6.1	
h	700°/120 Cs**..	237	78	50	20.5	26	62	9.4	
i	1000° Q_o Tp Q_w...	310	99	88	71	20	56	6.35	
j	550°/120 C_s**..	311	100.5	88	67.5	15	28	1.8	
k	1000° Q_o Tp Q_w...	401	134	123	82	12	41	0.8	
l	400°/120 C_s**..	397	133	123	74	8	22	0.8	
m	900° Q_o 675°/2 h C_a..	242	82.5	54.5	33	24	55	6.25	
n	900° Q_o Tp Q_w ...	247	83	67	47	25	66	10.25	
o	650°/120 C_s** ..	245	82.5	67	58	25	65	3.45	
p	900° Q_o 650°/6 h C_a	244	82	65.5	53.5	25	65	9.95	

Table 7, Part I.—Nickel Chromium Steels* (Tensile, Hardness and Impact Tests).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS_u†	Lit.
263									
q	900° Q_o 600°/2 h C_a	262	90.5	77.5	66	23	66	7.9	
r	850° Q_o Tp 2 h 530° Q_w ***	321	110	100	90	18	54	3.6	
s	850° Q_o Tp 2 h 600° Q_w †††	275	98	88	74	21	62	6.8	
t	850° Q_o Tp 2 h 650° Q_w ‡‡‡	248	89	78	60.5	24	66	9.0	
u	820° Q_o	495	182.5			14	37	1.5	
v	Same, Tp 200° Q_w	469	168.5			14.5	50	2.8	
w	Same, Tp 300° Q_w	436	152.5	126		14.5	53	0.55	
x	Same, Tp 400° Q_w	388	134	118		16	54	1.1	
y	Same, Tp 500° Q_w	331	112	102		19	56	3.9	
z	Same, Tp 600° Q_w	285	94.5	85		22.5	62	8.15	
aa	Same, Tp 650° Q_w	269	89.5	75.5		24	65	10.25	
bb	Same, Tp 700° Q_w	240	85	51	25	18	45	5.0	
cc	Same, Tp 700° C_a**	236	78	50	33	20	37	9.55	
264	900° Q_o Tp 650°/120 Q_w	247	81	67.5	53.5	26	70	8.6	(51)
	900° Q_o Tp 650°/120 C_a**	234	78	64.5	56.5	26	69	5.0	
265	830° Q_o		194	106.5	42				(3, 28, 71)
	Same, Tp 100°		190.5	121.5	52				
	Same, Tp 200°		174	136	90				
	Same, Tp 300°		158	129	111				
	Same, Tp 400°		145	121	102				
	825° Q_o Tp 600°	300	105	90		21.5	54.5	6.9	
	825° Q_o Tp 650°	293	104	87		19	47	7.5	
	845° Q_o Tp 600°	300	105	93		19	54	7.3	
	845° Q_o Tp 650°	293	103	88.5		18	49	7.2	
					IS_v				
267	850° C_a	477	180.5	133	2.3	13	40	2.5	(18, 30, 62, 65, 71)
	820° C_a	477§§§	176	139	2.3	10	39	2.35	
	Same, Tp 200° Q_w	477	174.5	132	2.6	11	44	2.35	
	Same, Tp 300° Q_w	444	162.5	128	2.0	12	48	1.65	
	Same, Tp 400° Q_w	418	141.5	126	2.1	14	52	1.95	
	Same, Tp 500° Q_w	351	116.5	105.5	3.7	18	56	4.7	
	Same, Tp 600° Q_w	277	94.5	82	11.7	23	65	10.4	
	Same, Tp 650° Q_w	262	85	72.5	14.6	25	67	11.5	
	820° Q_o Tp 400° Q_w	418	143	137	2.8	13	52	2.35	
	820° Q_o Tp 500° Q_w	364	123	112	5.8	16	56	5.1	
	820° Q_o Tp 620° Q_w	269	ScH = 44						
	820° Q_o Tp 650° Q_w	262	90	74	13.8	24	57	11.9	
	A	255	ScH = 45						
268	W_{gf} 795° C_a	430	183	144.5	2.4	11	38	2.0	(28)
	W_{salt} 795° C_a	444	186	141	2.55	13	34	2.0	
	W_{gf} 825° C_a	430	183	143.5	2.65	12.5	39	2.15	
					PL				
269	830° C_a		173.5	103	38				(3)
	Same, Tp 100°		161.0	109	55.5				
	Same, Tp 200°		152.0	128	93.5				
	Same, Tp 300°		145.0	140.5	104				
	Same, Tp 400°		132.5	115.5	91.5				
	Same, Tp 500°		110.0	102.5	89				
	Same, Tp 600°		95.5	75.5	61				
270	900° Q_o Tp 650°/120 Q_w	245	81	58	36	24	62	8.2	(28, 51)
	900° Q_o Tp 650°/120 C_f**	239	80	55	36	24	65	6.1	
								IS_y†	
271	As forged	279	80			7			(136)
	1150° Q_o		82	35		52‖‖	52¶¶¶	24.5	
273	1000° Q_o	237	83.5	49		22	37		(136)
	1100° Q_o	214	80	45.5		35	42.5		
	1200° Q_o	203	75	36.5		47	48.5		
								IS_u†	
274	1000° Q_w		77	33		73	68		(52)
275	As received, R	196	70	38		45 to 25	57 to 46	5.5	(71)
	950° C_a		70	29		57	58		
	950° C_f		63	27		48.5	51		
	900° Q_w		74.5	30		62	59		
	As received, Tp 300° 60 Q_w		79	42		40.5	51		
	As received, Tp 400° 60 Q_w		80.5	49.5		35	51		
	As received, Tp 500° 60 Q_w		70.5	36.5		29.5	43		
	As received, Tp 600° 60 Q_w		61.5	37.5		28	44.5		
	Tp 400°/360 Q_w		73	49.5		40	52		
	Tp 350°/120 Q_w		74	39.5		47.5	52		
	900° Q_w Tp 400°/60		71.5	33		58	54		

Table 7, Part I.—Nickel Chromium Steels* (Tensile, Hardness and Impact Tests).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS_w†	Lit.
276	BHN: 900° Q_w = 187; 1000° Q_w = 187: 1100° Q_w = 293								(71)
277	950° Q_w		75	45		30		7.5	(71)
278	As for service	ca. 160	Scleroscope hardness = ca. 19						(20)

* See Table of Chemical Analyses, p. 486
† For meaning of subscripts, v. p. 396.
‡ PL = 23.5.
§ ScH = 40.
¶ Bars 3 in. diam.
** C_a = Cooled at 0.3° per min. between 600 and 400°.
†† ScH = 28.
‡‡ Large size Charpy test piece.
§§ ScH = 36; EL = 82.5.
‖‖ ScH = 28; EL = 70.
¶¶ ScH = 29; EL = 60.5.
*** ScH = 50.
††† ScH = 45.
‡‡‡ ScH = 38.
§§§ ScH = 69.
‖‖‖ On 75 mm diam.
¶¶¶ 15 mm diam.
**** ScH = 22.
†††† Additional values of impact strength for steels Nos. 262 and 263.

KN	Trt	a	b	c	d	e	f	g	h	bb	cc	ee
262	IS_v	1.3	1.2	1.3	0.6	0.8	2.4	6.1	10.1	1.1	2.5	6.9

Trt	l	m	n	o	p	Trt	j	k	l	m
IS_v	7.6	2.5	0.55	0.4	7.1	IS_x	12.0	5.0	11.0	5.3

Trt	n	o	p	r	s	t	x	y	z	aa	ee
IS_x	0.8	0.6	9.8	7.8	2 5	8.9	10.2	1.8	12.0	7.6	6.3

Trt	jj	kk	ll	mm	Trt	nn	oo	pp	Nos. 262j to 262aa tested
IS_x	7.6	4.2	8.2	4.3	IS_z	7.5	7.8	6.9	on the Guillery Mach.

KN	Trt	u	v	w	x	y	z	aa
263	IS_v	1.6	2.9	0.7	1.7	3.5	8.9	12.8

Table 7, Part II.—Compression Tests on Ni-Cr Steels

Key No.	Treatment	l, in.	Diam., in.	UCS	YP_C	PL_C	EL_C	Lit.
243	Hot rolled	3.5	0.75	45	28	26.5		(128)
262	830° C_a A 788°/30 C_f	3	0.75		43	39.5		(109, 110)
	830° Q_o 600° Q_o	3	0.75	93.5	91.5	86	87	
	830° Q_o 788° Q_o 650°/60 C_f	3	0.75	70.5	70	68.7	69	
	830° Q_o 788° Q_o 650°/60 Q_w	3	0.75	70	68.5	64.5	64.5	
269	v. Fig. 40							

Specimens 0.564 in. × 0.564 in. diam. Loaded to 315 kg/mm² (28)

Key No.	257	257	263	263	265
Treatment	825° Q_o	845° Q_o	824° Q_o	845° Q_o	824° Q_o
Permanent set	23%	25%	12.7%	10.2%	2.8%

Table 7, Part III.—Torsion Tests on Ni-Cr Steels

Key No.	Treatment	USS*	TMR	YP_S	PL_S	EL_S	Total twist	Lit.
243	R_h (2 in. × 5/8 in. diam.)	32.5_c	43.5	19.5	17			(128)
	R_h (2 in. × 5/8 in. outside diam. × 1/2 in. inside diam.)			17	16			
257	825° Q_o Tp 600°	61.5_c	82.5	64.5			884°	(28)
	825° Q_o Tp 650°	59.5_c	79	50.5			886°	
	845° Q_o Tp 600°	66.5_c	89	67.5			1094°	
	845° Q_o Tp 650°	59_c	79	50			1104°	
262	830° C_a 788°/30 C_f†			25.5	24			(109, 110)
	830° Q_o 788°/30 Q_o 650° C_f†				44	44.5		
	Same, but 650° Q_w†				44	44		
	830° Q_o 600° Q_o†			59.5	51	51.5		

Table 7, Part III.—Torsion Tests on Ni-Cr Steels.—(*Continued*)

Key No.	Treatment	*USS**	*TMR*	YP_S	PL_S	EL_S	Total twist	Lit.
263	850° Q_o Tp 530° Q_w‡	67.5_c	90.5	61.5			310°	(28, 65)
	850° Q_o Tp 600° Q_w‡	62.5_c	83	58.5			440°	
	850° Q_o Tp 650° Q_w‡	57.5_c	76.5	51			600°	
265	825° Q_o Tp 650°	69.5_c	92.5	58.5			1050°	(28)
	845° Q_o Tp 600°	70_c	93	66.5			954°	
	845° Q_o Tp 650°	65.5_c	87	58			886°	
267	830° Q_o Tp 620°	61.5_c	82.5	51.5			399°	(65)
	820° H_a‡	106_c	141	88			27°	

* Subscript $_c$ calculated on assumption of uniform stress throughout section.
† Specimen 2¼ in. × ½ in. diam.
‡ Specimen 1¾ in. × ⅝ in. diam.

Table 8.—Ni-Cu Steels*

Key No.	Treatment	*BHN*	*ScH*	*UTS*	*YP*	*PL*	*El*	*RA*	Lit.
279	As cast	139		60.2	42.9		25	42.5	(54)
280	As received			67.7	37.1			57	(93)
281	As cast	149		64.5	43.0		28	47	(54)
282	As forged			99.0	69.0		11.5	18	(54)
283	800° C_a	320	37	105.5	90.1	56.2	11†	27	(23)
	800° Q_o Tp‡	546	57	220.3	192.2		7.5†	36.5	
284	As forged			104.8	79.9		11	24.5	(54)
285	As rolled	307		61.1	40.7		20.5	45	(58)
286	As forged			77.6	58.1		22	48	(54)
287	As forged			92.9	60.5		11.5	23	(54)
288	As rolled	300		54.5	36.5		25	54	(58)
289	780° C_a	326	35	122.0	120.8	38.7	6†	15	(23)
	780° Q_o Tp‡	550	60	142.1?		105.5			
290	760° C_a	279	37	98.2	92.5	49.9	11.5†		(23)
	760° Q_o Tp‡	642	70	176.9?		98.4	20†	1	
291	As forged			79.2	56.2		19	38	(54)
	850° Q_w Tp 400°			§	88.6				
292	As rolled			62.4	39.1		20	47	(58)
293	As forged			90.1	56.0		12.5	17	(54)
294	As cast	166		70.3	53.8		20	33	(54)
295	800° C_a	292	38	101.0	94.4	49.2	12†	38	(23)
	800° Q_o Tp‡	555	63	230.5	196.1	130.7	4.5†	8	
296	780° C_a	285	38	103.7	92.5	59.8	12†	45	(23)
	780° Q_o Tp‡	578	68	209.4	183.8		1†	2	
297	As forged			88.9	56.7		14	28.5	(54)
298	As forged			70.7	49.5		18.5	33	(54)
	850° Q_w Tp 400°			§	129.6				
299	780° C_a	396	40	108.4		49.2	1†		(23)
	780° Q_o Tp‡	530	52	176.9		98.4	1†	14	
300	As forged			93.6	93.6		1	0	(54)
301	As received			62.4	41.6	30.8	16.5	29	(132)
	Annealed			61.6	40.5	34.5	21.5	33	
	Tp_o			70.3	49.2	43.2	19.5	36	
302	As rolled			81.0	50.9		22	51	(101)
	Annealed			75.4	44.8		25	48	
	815° Q_o Tp 425°			121.3	108.3		13	49	
	815° Q_o Tp 315°			140.6	130.1		12	46	
303	As received			85.1	60.8	35.6	3	5	(132)
	Annealed			83.7	58.0	46.9	14.5	39	
	Tp_o			60.6		59.4	0	0	
304	As received			71.0	40.3		42.5	61.5	(31)
305	As received			67.5	36.4		42	54	(31)
306	As forged		16	49.9	34.6		22.5	62.5	(22)
	Annealed		17	44.3	28.3		30	64	
307	As received			53.1	44.7		28	65.5	(31)
308	As received			52.8	45.4		25.5	71.5	(31)
309	As forged		18	57.8	44.7		28	65	(22, 31)
	Annealed		21	61.6	50.1		24	60	
310	As received			106.1	84.4		8	16	(31)
311	As forged		22	59.0	50.9		25	54	(22)
	Annealed		24	75.5	63.9		19	49.5	
312	As forged		27	75.6	64.5		20	53	(22)
	Annealed		26	72.4	61.9		20	62.5	

Table 8.—Ni-Cu Steels.*—(*Continued*)

Key No.	Trt	*ScH*	*UTS*	*YP*	*El*	*RA*	Lit.
313	F	37	104.5	98.1	13	37	(22)
	A	33	105.4	101.1	16	52	
314	F	39	130.1	110.6	13	40.5	(22)
	A	33	106.4	102.5	12	39	
315	F	40	117.1	101.4	7	16.5	(22)
	A	34	106.5	103.1	10	38	
316	F	41	129.3	114.2	10	27	(22)
	A	33	107.5	96.8	11	40.5	
317	F	41	144.0	119.5	7.5	17.5	(22)
	A	38	114.0	91.2	10.5	16	
318	F	42	143.0	131.3	6	7	(22)
	A	42	108.9	89.0	4	1	

Key No.	Treatment	*IS*‖
283	800° Q_o Tp 175°/3 h	1.0
289	780° Q_o Tp 175°/3 h	0.8
290	760° Q_o Tp 175°/3 h	0.5
295	800° Q_o Tp 175°/3 h	1.1
296	780° Q_o Tp 175°/3 h	0.4
299	780° Q_o Tp 175°/3 h	0.5

* For analyses *v.* p. 486.
† Dimensions of test piece = 2 in. × 0.3 in. diam.
‡ Tp 175°/3 h.
§ Broke in thread.
‖ Izod machine. Specimens 0.45 in. diam. Area of notch 0.12 in.² (23).

Table 9.—Nickel Vanadium Steels* (Tensile, Hardness and Impact Tests)

Key No.	Treatment	*BHN*	*UTS*	*YP*	*PL*	*El*†	*RA*	*IS*‡	Lit.
319	N 900° C_a	170	60.3		44.6	20	70		(55)
	850° Q_w	311	115.3		96.6	9	43.5	IS_y	
320	N 900° C_a	235	95.7		48.0	7	8	6	(55)
321	850° C_a		89.5	64.4	40.0	15	32		(71)
	850° Q_o Tp 600°	282	94.2	55.6		12	21.5		
	850° Q_o Tp 700°	235	91.0	70.0	47.1	16	29		
	v. Figs. 29 and 46. *BHN* = 600 (Q_w); 532 (Q_o); 269 (C_a); 255 (C_m)								
322	N 900° C_a	277	89.6		46.1	11	25.5	6	(55)
323	N 900° C_a	187	66.3		55.2	21.5	57	31	(55)
	850° Q_w	387	117.0		97.0	8	44	11	
324	N 900° C_a	217	72.3		64.0	16	48	16	(55)
	850° Q_w	269	137.0		132.2	4	16.5	6	
325	850° C_a		101.5	70.0	44.7	11.5	16.5		(71)
	850° Q_o Tp 650°	302	104.0	61.9	38.8	10	21.5		
	850° Q_o Tp 700°	241	97.2	77.8	52.6	11.5	20		
	v. Figs. 29 and 46. *BHN* = 600 (Q_w); 578 (Q_o); 285 (C_a); 265 (C_m)								
326	N 900° C_a	166	77.0(*EL* = 56.2)			16	61	6	(56)
	850° Q_w	375						3	
327	N 900° C_a	255	96.2		55.4	5	8.5	5	(55)
328	N 900° C_a	183	60.8		44.8	17.5	38	5	(55)
	850° Q_w	156	54.9		40.3	18	40	9	
329	N 900° C_a	235	84.8		54.8	7	12	5	(55)
330	N 950° C_a	196	69.2(*EL* = 52.0)			20	46	6	(56)
	850° Q_w	460						2	
331	840° C_a§	255	102.1	61.4	35.9	16	47	IS_u‖	(23)
	840° Q_o Tp¶	**	202.8		91.4	9	37.5	1.2	
332	827° Q_o Tp 205°	512††	205.8	157.9	119.5	0	3.5	1.2	(23)
333	800° C_a	302‡‡	97.7	72.5	58.3	19.5	48.5		(23)
	800° Q_o Tp¶	627§§	241.3	194.2		5	8	0.8	
334	R¾ in. diam		107.3	79.1		17_a	36		(8)
	800° C_a		85.6	72.9		22_a	51		
						10_c			
	R 3 × ⅜ in. plate		111.6	64.5	*EL*	20_a	12	IS_y	
335	N 900° C_a	183	73.0		57	19	44	8	(56)
	850° Q_w	460	129.0		129	0	2	3	

Table 9.—Nickel Vanadium Steels* (Tensile, Hardness and Impact Tests).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El†	RA	IS_y‡	Lit.
336	N 900° C_s..........	179	67.8		49.0	21	44	8	(56)
	850° Q_w............	402						3	
337	N 900° C_s..........	192	76.0		57.6	18	48	10	(56)
	850° Q_w............	293	157.0		148	11	48	8	
338	N 900° C_s..........	235	78.2		61.8	17.5	45	8	(56)
	850° Q_w............	321	151.2		144	10	46.5	5	
339	N 900° C_s..........	166	61.0		49.0	24.5	44	20	(56)
	850° Q_w............	302	154.0		146	10	46	9	

* For analyses *v.* p. 487.

† Dimensions of test pieces; 100 mm × 13.8 mm diam. except for Nos. 331–333 where they are 2 in. × 0.300 in. diam. and for Nos. 321, 325, 334, dimensions 2 in. × 0.564 in. diam.

‡ For meaning of subscripts *v.* p. 396.

§ ScH = 38.

‖ Test piece 0.35 in. diam. Area of notch = 0.074 in.²

¶ Tp 175°/180.

** ScH = 43.

†† ScH = 69.

‡‡ ScH = 26.

§§ ScH = 60.

Table 10.—Vanadium Steels (Tensile, Hardness and Impact Tests)

Key No.	Treatment	Hardness ScH	UTS	YP	PL	El	RA	IS	Lit.
340	815° Q_o........	44	97.7	79.4		3			(53)
	870° Q_o........	55	137.2	118.2		4.5			
	925° Q_o........	58	142.0	121.0		7			
	Same, Tp 540°	38	87.1	80.6		14			
	Same, Tp 595°	37	83.3	74.1		15			
	Same, Tp 650°	35	74.5	68.9		15			
	Same, Tp 705°	32	61.9	53.6		18			
	Same, Tp 760°	28	53.1	42.8		20			
341	R ¾ in.*........	BHN	106.9	67.7		6.5_a	7		(8)
342	As received.....	166	60.0	52.8		24_a	70		(106, 107)
	900° C_a........	104	39.5	27.7		36_a	74.5		
	A 950° C_f†.....	82	36.2	20.8		39_a	73		
	850° Q_w Tp 400° C_a	116	42.6	28.9		33_a	79		
	850° Q_w Tp 500° C_a	121	48.5	30.5		35.5_a	77.5		
	850° Q_w Tp 700° C_a	116	44.2	32.1		35_a	75		
343	As received.....	143	63.7	46.4		23_a	55		(106, 107)
	900° C_a........	126	50.4	33.4		32_a	62		
	A 950° C_f†.....	94	40.0	19.5		37.5_a	62		
	850° Q_w Tp 400° C_a	157	59.8	40.9		31.5_a	67		
	850° Q_w Tp 500° C_a	159	61.8	41.5		29.5_a	66		
	850° Q_w Tp 700₀ C_a	145	56.2	39.0		31_a	69		
								IS_u	
344	As cast.........	156	56.8	26.2	15.8	23.5	29.5	0.9	(95)
	A 925° C_f......	152	55.9	28.1	22.5	27.5	43	2.1	
	925° C_a........	162	62.3	36.9	35.5	26.4	47	2.6	
345	As received.....		104.5	59.8		4.5_a	3.5		(106)
	900° C_a........		83.1	45.3		17_a	32		
	A 950° C_f†.....		59.4	25.2		28_a	44.5		
	850° Q_w Tp 400° C_a		146.4	119.6		4.5_a	9		
	850° Q_w Tp 500° C_a		134.4	89.8		9.5_a	23		
	850° Q_w Tp 700° C_a		95.9	63.0		17_a	35		
346	As received.....	252	93.7	61.4		10.5_a	17		(106, 107)
	900° C_a........	202	72.4	46.0		23_a	45.5		
	A 950° C_f†.....	136	55.2	22.7		26_a	43		
	850° Q_w Tp 400° C_a	286	105.0	80.2		16.5_a	44.5		
	850° Q_w Tp 500° C_a	266	95.6	74.0		18_a	51		
	850° Q_w Tp 700° C_a	212	79.1	56.7		24.5_a	57.5		
347	As received.....		109.9	61.4		9.5_a	18		(106)
	900° C_a........		100.8	48.8		11.5_a	20.5		
	A 950° C_f†.....		63.2	25.2		18_a	27.5		
	850° Q_w Tp 400° C_a		146.4	112.0		11.5_a	33.5		
	850° Q_w Tp 500° C_a		142.2	100.8		13_a	35.5		
	850° Q_w Tp 700° C_a		95.0	66.1		19.5_a	44		
348	As received.....		110.8	69.3		13_a	23		(106)
	900° C_a........		86.1	47.2		19.5_a	32		
	A 950° C_f†.....		65.2	26.7		20_a	28		

Table 10.—Vanadium Steels (Tensile, Hardness and Impact Tests).—(Continued)

Key No.	Treatment	BHN	UTS	YP	PL	El	RA	IS_y	Lit.
348	850° Q_w Tp 400° C_a		131.0	103.9		14_a	41		
	850° Q_w Tp 500° C_a		125.2	90.7		16_a	39.5		
	850° Q_w Tp 700° C_a		88.8	64.5		21_a	50		
349	As received.....	228	84.5	61.4		18_a	41.5		(106, 107)
	900° C_a........	196	66.8	45.8		23_a	48.5		
	A 950° C_f†.....	120	48.5	25.8		32_a	39		
	850° Q_w Tp 400° C_a	236							
	850° Q_w Tp 500° C_a	227							
	850° Q_w Tp 700° C_a	195							
350	N 900° C_s‡.....	286	88.5		43.8	8	20	3	(55, 119)
	850° Q_w........	600	115.3		103.0	6	12	0	
351	R (bar)........		75.4	58.9	36.9	23_a	51		(8, 128)
	800° C_a........		57.1	44.4		29.5_a	59.5		
	R 3 × ⅝ in.....		69.7	53.1		{ 19_a 31_c }	51.5		
352	N 900° C_s‡.....	140	43.8		30.2	24	62.5	30	(55, 119)
	850° Q_w........	156	54.6		49.2	22.5	66.5	10	
353	820° C_a§.......	208‖	75.3	55.7	49.9	22	52		(23)
	820° Q_o Tp¶...	196**	81.1	67.0	59.7	12	45	4.3††	
354	R ¾ in.*........		120.0	68.0		8.5_a	10		(8)
355	780° C_a........	217‡‡	82.0	54.5	42.1	7.5	21		(23)
	780° Q_o Tp¶...	340§§	106.1		77.3	2.5	31	1.4‖	
356	N 900° C_s‡.....	159	52.9		41.1	20	69	20	(55, 119)
	850° Q_w........	163	68.5		41.4	20	63	13	
357	R 3 × ⅝ in.....		85.9	65.9		15_c	34.5		(8)
358	N 900° C_s‡.....	286	92.3		47.4	8	20	3	(55, 119)
	850° Q_w........	512	118.2		105.1	9	20	0	
359	R ¾ in.........		134.6	102.1		7_a	7.5		(8)
360	950°/6 h C 12 h		56.5	18.9		22_a	41.5		(9)
361	N 900° C_s‡.....	217	57.7		43.4	15.5	58	19	(55, 119)
	850° Q_w........	217	73.1		49.2	17.5	61	11	
362	N 900° C_s‡.....	332	96.2		56.2	4	19	4	(55, 119)
	850° Q_w........	555	130.1		112.2	3	10	0	
363	R ¾ in.*........		132.2	92.6		7.5_a	9		(8)
364	R ¾ in.*........		41.1	32.1		37_a	72		(8)
365	N 900° C_s‡.....	217	61.1		45.4	15	71	20	(55, 119)
	850° Q_w........	207	95.6		61.8	12	60	12	
366	R ¾ in.*........		128.4	85.0		10_a	17.5		(8)
367	N 900° C_s‡.....	286	87.5		58.3	8	26	3	(55, 119)
	850° Q_w........	532	121.3		101.3	5	6.5	0	
368	N 900° C_s‡.....	159	56.4		44.8	19	72.5	30	(55, 119)
	850° Q_w........	156	71.7?		52.1	14	67	18	
369	N 900° C_s......	262	94.9		64.1	9	31	3	(55, 119)
	850° Q_w........	321	112.2		101.1	13	13	3	
370	N 900° C_s‡.....	159	50.4		39.4	15	68	25	(55, 119)
	850° Q_w........	156	55.4		42.3	12	60	25	
371	950°/6 h C 12 h		55.1	22.1		24.5_a	52		(9)
372	N 900° C_s......	286	91.4		48.1	9	34	2	(55, 119)
	850° Q_w........	652	105.3		75.6	11.5	18.5	0	
373	N 900° C_s‡.....	99	47.1		26.8	26	74	22	(55, 119)
	850° Q_w........		45.6		29.5	21	61		
374	N 900° C_s‡.....	262	85.2		58.2	16	28.5	3	(55, 119)
	850° Q_w........	321	99.7		67.7	3	6.5	0	
375	N 900° C_s‡.....	255	98.9		55.3	14	25	5	(55)
	850° Q_w........	578	95.3		58.7	11	41	0	
376	N 900° C_s‡.....	143	46.5		25.5	17	61	6	(55, 119)
	850° Q_w........	121	44.3		26.3	26.5	58.5	3	
377	950°/6 h C 12 h		52.6	26.8		25_a	53		(9)
378	N 900° C_s‡.....	109	43.8		24.8	30	63	2	(55, 119)
	850° Q_w........	99	42.5		25.9	30	65	3	
379	N 900° C_s‡.....	143	51.7		28.9	20	34	3	(55, 119)
	850° Q_w........	105	45.8		35.8	27.5	41	2	

TABLE 10.—VANADIUM STEELS (TENSILE, HARDNESS AND IMPACT TESTS).—(*Continued*)

Key No.	Treatment	*BHN*	*UTS*	*YP*	*PL*	*El*	*RA*	IS_y	Lit.
380	N 900° C_s‡.....	118	46.5		25.3	31	53	4	(55,
	850° Q_w........	124	46.9		26.2	22	56	2	119)
381	N 900° C_s‡.....	179	62.5		31.6	12	37.5	0	(55,
	850° Q_w........	187	58.2		42.3	17.5	33	0	119)
382	950°/6 h C 12 h		53.1	23.6		23_a	31.5		(9)
383	Same..........		58.3	28.3		10_a	10		(9)

Compression test on No. 351 (hot rolled):

$$UCS = 71, YP_C = 45, PL_C = 38 \text{ kg/mm}^2 \text{ (128)}.$$

* Diameter.
† A 950°/18 h C_f.
‡ Tensile specimen 100 mm × 13.8 mm diam.
§ Tensile specimen 2 in. × 0.300 in. diam.
‖ *ScH* = 24.
¶ Tp 175°/3 h.
** *ScH* = 27.
†† IS_u: Specimen 10.09 mm diam., area at notch = 52.6 mm².
‡‡ *ScH* = 22.
§§ *ScH* = 40.
‖‖ IS_u: Specimen 11.4 mm diam., area at notch = 77.8 mm².

TABLE 10*A*.—SHEAR AND TORSION TESTS ON VANADIUM STEELS

Key No........	350	352	358	361	362	365	367	368	369	372
USS..........	55.5	23	50.5	30	52	29	43	24	38	44
Key No........	373	374	376	378	379	380	381	(N 900° C_s) Fremont machine used (119)		
USS..........	24	40	24	24	27	27	31			

Key No.	Treatment	*USS*	YP_S	PL_S	*Tw*	Lit.
344	As cast..............	40	16	11.5	697°	(95)
	A 925° C_f...........	44.5	24	21.5	694°	
	925° C_a.............	48	27	24.5	1045°	
351	Hot rolled*..........	56_o†	31.5	24		(128)

* 2 in. × ⅝ in. diam.
† Calculated on assumption of uniform stress throughout section.

TABLE 11.—ELASTIC PROPERTIES

Key No.	Treatment	$10^{-2}E$	$10^{-2}G$	Lit.
	Carbon Steels			
1	Normalized..............		83	(90, 110)
	Annealed................		79.5	
2	R_h 14.3 mm*............	190		(46)
	D 13.0 mm............	196		
	D 12.0 mm............	192		
	D 10.8 mm............	190		
	D 9.7 mm............	187		
	R_h 5.20 mm*............	200		
	D 3.97 mm............	215		
	D 2.83 mm............	210		
	D 2.37 mm............	210		
	D 2.00 mm............	200		
	D 1.70 mm............	198		
	D 1.37 mm............	200		
	D 1.18 mm............	201		
	D 0.98 mm............	200		
3	Forged..................	208	79†	(15, 34, 141)
	A 850°..................	206		
	850° Q_w................	211		
	850° Q_o 80°.............	206		
	1000° Q_w...............	207		
	Same, Tp 550°...........	207		
	1000° Q_o................	208		
5	Rolled..................	210		(123)
	A 670°/30...............	209		
7	A 900°..................	206	82‡	(29, 74, 141)
	850° Q_w................	200		
	Same, Tp 550°...........	199		
	850° Q_o 80°.............	206		
	Same, Tp 550°...........	200		
	900° Q_o.................	199	82	
8	850° Q_w................	210		(141)
	Same, Tp 550°..........	207		
	Same, Tp 650°..........	207		
	850° Q_o 80°.............	206		
	Same, Tp 550°...........	205		
13	R_h 15.0 mm*............	202		(46)
	D 14.3 mm............	198		
	D 13.8 mm............	199		
	D 13.2 mm............	200		
	D 12.7 mm............	200		
	D 11.2 mm............	201		
	D 8.2 mm............	199		
14	A 760° C_f...............	204	83	(140)
16	Rolled..................	218		(86, 123)
	A 675° 30............	213	(*v. also*	
	A 1150° 30............	220	Fig. 23)	
	A 900° 30............		82	
19	Annealed................	204	82.7	(74, 110)
	N 815°..................		83	
	845° Q_w 565° C_a.........		84	
22	R_h.....................	198		(141)
	A 850°..................	199		
	850° Q_w Tp 550°.........	197		
	850° Q_o Tp 550°.........	198		
26	Forged..................	226		(15)
	Annealed................	213		
	Hardened................	211		
27	775° Q_w 650° C_f..........		85.5	(110)
32	N 845°..................		82	(46, 110)
	790° Q_w Tp 650°.........		85	
	R_h 5.37 mm*............	205		
	D 4.36 mm............	202		
	D 3.60 mm............	193		
	D 3.00 mm............	208		
	D 2.48 mm............	199		
	D 1.98 mm............	200		
36	Forged..................	230		(15)
	Annealed................	214		
	Hardened................	208		
41	R_h 15.0 mm*............	209		(46, 141)
	D 14.3 mm............	207		
	D 13.9 mm............	205		
	D 13.2 mm............	205		
	D 12.7 mm............	201		
	D 11.2 mm............	200		
	750° Q_w................	205		
	Same, Tp 350°...........	214		
	750° Q_o 80°.............	206		

TABLE 11.—ELASTIC PROPERTIES.—(*Continued*)

Key No.	Treatment	$10^{-2}E$	$10^{-2}G$	Lit.
	Carbon Steels			
42	R_h	209		(141)
	750° Q_w	204		
	Same, Tp 350°	214		
	750° Q_o 80°	204		
45	A 900°	200	82	(74)
	900° Q_o	192	78	
51	A 850°	209		(46, 141)
	750° Q_w Tp 650°	200		
	R_h 5.30 mm*	219		
	D 4.58 mm	212		
	D 4.22 mm	205		
	D 3.84 mm	197		
	D 3.43 mm	200		
56	A 900° (*v. also* Fig. 23)		80.5	(86)
58	F	211		(15)
	A	217		
	H	203		
59	A 900°	206	82.7	(74)
	900° Q_o	193	78.7	
60	R_h	208		(110, 141)
	A 790° C_t		83.5	
	A 850°	205		
	750° Q_w	199		
	850° Q_w	197		
	790° Q_o Tp 450°		84.0	
	790° Q_o Tp 650°		86.5	
61	R_h 15.0 mm*	201		(46)
	D 14.3 mm	199		
	D 13.9 mm	199		
	D 13.2 mm	200		
	D 12.7 mm	197		
	D 12.3 mm	198		
64	A 900°	204	83.8	(74)
	900° Q_o	193	80.0	
68	F	200		(15, 74, 110, 141)
	A	209	83.5	
	N 860°		82.0	
	750° Q_w	202		
	Same, Tp 650°	202		
	850° Q_w Tp 650°	199		
	900° Q_o	192	80.0	
	Same, Tp 460°		84.0	
70	A 760° C_t	215	82.0	(140)
75	F	208		(15)
	A	200		
77	A 900°	201	79	(74)
	900° Q_o	189	75	
78	F	206		(15)
	A	208		
80	F	213		(15)
	A	207		

* Diameter.
† λ (obs.) = 0.314.
‡ λ (obs.) = 0.265–0.275.

TABLE 11.—ELASTIC PROPERTIES.—(*Continued*)

Key No.	Treatment	$10^{-2}E$	$10^{-2}G$	Lit.
	Cast Iron			
100	As cast	83		(124)
102	A 770–840°	17.6		(63)
106	As cast	84.3–105.5	45–57.7	(21)
111	As cast	85		(21, 124)
114	As cast	64.5		(124)
118	As cast	71		(124)

TABLE 12.—SPECIFIC GRAVITY

For changes in volume due to tempering, *see* p. 477

Key No.	Treatment	d_4^{20}	Lit.
	Carbon Steels		
3	Normalized	7.87	(15, 115)
	900° Q_w	7.866	
4	Annealed	7.871	(15)
5	Cold worked	7.855	(19, 71, 103, 116)
	Same, Tp 600°	7.857	
	R_h or 900° Q_w	7.862	
	Normalized	7.874	
7	A or 850° Q_w	7.861	(15)
8	N 1000°	7.856	(115)
	800–1000° Q_w	7.849	
9	Annealed	7.858	(15)
	850° Q_w	7.841	
10	Annealed	7.863	(15)
11	Annealed	7.854	(15)
13	Normalized	7.854	(71)
	850° Q_o	7.842	
15	N 1000°	7.840	(115)
	750–1000° Q_w	7.821	
16	Annealed	7.867	(15, 103)
	850–1000° Q_w	7.836	
18	Annealed	7.834	(15)
19	Annealed	7.853	(15)
	850° Q_w	7.831	
20	1000° Q_w	7.840	(102)
	Same, Tp 200°/4 h	7.850	
	Same, Tp 450–600°	7.860	
21	N 1000°	7.839	(15, 96, 115)
	700° Q_w	7.838	
	900° Q_w	7.833	
	1000° Q_w	7.822	
	Annealed	7.855	
24	N 1000°	7.837	(115)
	750–1000° Q_w	7.789	
26	F or A	7.817	(15)
	800° Q_w	7.786	
29	Annealed	7.857	(15)
32	Cold worked	7.799	(46)
	Same, annealed	7.824	
33	N 1000°	7.822	(115)
	750–1000° Q_w	7.797	
34	Annealed	7.860	(15)
36	F or A	7.800	(15)
	800° Q_w	7.757	

TABLE 12.—SPECIFIC GRAVITY.—(*Continued*)

Key No	Treatment	d_4^{20}	Lit.
	Carbon Steels		
37	Annealed	7.860	(15)
38	Hardened	7.81	(19)
39	Normalized	7.843	(115)
	750–1000° Q_w	7.805	
41	Annealed	7.829	(15)
	850° Q_w	7.777	
43	Annealed	7.854	(15)
45	850° Q_w	7.789	(3, 71)
	R_c greatly	7.830	
	Same, A 600° or N	7.836	
46	Normalized	7.843	(15, 103, 115)
	Annealed	7.852	
	750° Q_w	7.784	
	900–1000° Q_w	7.776	
49	Annealed	7.851	(15)
51	Annealed	7.84	(15, 46)
	Cold worked	7.835	
53	Normalized	7.839	(19, 102, 115)
	Annealed	7.849	
	750° Q_w	7.765	
	1000° Q_w	7.752	
56	765° Q_w	7.74	(103)
	900–1000° Q_w	7.73	
58	F or A	7.833	(15)
	800° Q_w	7.749	
60	Annealed	7.82	(15, 115)
	850° Q_w	7.75	
	1000° Q_w	7.76	
62	Hardened	7.76	(19)
63	Annealed	7.840	(15)
65	Annealed	7.838	(15)
66	N 1000°	7.79	(115)
	750° Q_w	7.71	
	1000° Q_w	7.66	
67	Annealed	7.82	(103)
	765° Q_w	7.76	
	900° Q_w	7.71	
68	F or A	7.826	(15, 102)
	800° Q_w	7.773	
	Same, Tp 200°/4 h	7.783	
	Same, Tp 600°/1 h	7.824	
	1000° Q_o	7.821	
	Same, Tp 200°/4 h	7.831	
	Same, Tp 600°/1 h	7.832	
	1100° Q_w	7.729	
	Same, Tp 200°/4 h	7.759	
	Same, Tp 600°/1 h	7.796	
69	Hardened	7.79	(19)
70	Hardened	7.75	(19)
73	Annealed	7.837	(15)
75	F or A	7.819	(15)
	800° Q_w	7.740	
	Hardened*	7.718	
76	Annealed	7.831	(15)

TABLE 12.—SPECIFIC GRAVITY.—(*Continued*)

Key No.	Treatment	d_4^{20}	Lit.
78	As forged	7.82	(15, 71)
	Annealed	7.825	
	800° Q_w	7.73	
79	Annealed	7.823	(15)
80	As forged	7.793	(15, 115)
	Annealed	7.803	
	750° Q_w	7.439	
	1000° Q_w	7.373	
83	Annealed	7.802	(15)
	Cast Iron		
101	A 840–880°	7.6	(63)
102	A 770–840°	7.6	(63)
103	As cast	7.58–7.73	(78)
106	As cast	7.03–7.20	(21,78)
	Chromium Steels		
141	Heated to cherry red, and Q_w	7.76	(19)
145		7.76	
169		7.70	
178	1000° Q_o	7.73	(71)
	Same, Tp 820° Q_w	7.73	
180	950° Q_o Tp 250° Q_w	7.755	(71)
	950° Q_o Tp 750° Q_w	7.77	
182	1000° Q_o	7.68	(71)
	Same, Tp 820° Q_w	7.70	
183	1000° Q_o	7.72	(71)
	Same, Tp 820° Q_w	7.74	
191	As received	7.60	(36)
	Chrome-Vanadium Steels		
203	850° Q_o	7.817	(71)
	Same, Tp 650° Q_w	7.839	
	Copper Steels		
230	Hardened	7.835	(19)
231	As rolled	7.87	(6)
236	Hardened	7.84	(19)
237	Hardened	7.85	(19)
239	Hardened	7.75	(19)
	Nickel-Chromium Steels		
262	I†	7.846	(51)
	II†	7.846	
	I Tp 600° Q_w†	7.849	
	II Tp 600° C_f†	7.850	
263	830° Q_o	7.83	(51, 71)
	Same, Tp 600°	7.85	
	I Q_w 600° Q_w, 600° C_f†	7.8475	
	I C_f 600° C_f, 600° Q_w†	7.8469	
	II Q_w 600° Q_w, 600° C_f†	7.8470	
	II C_f 600° C_f, 600° Q_w†	7.8466	
267	820° C_a	7.82	(71)
	820° Q_o 630° Q_w	7.835	

* From a very high temperature.
† I = 1000° Q_o 650°/2 h Q_w.
II = 1000° Q_o 650°/2 h C_f.

TABLE 13.—THERMAL PROPERTIES

C_0^{100} = mean specific heat between 0 and 100°C, joules g^{-1}

k_0^{100} = mean thermal conductivity between 0 and 100°C, joules cm^{-2} sec^{-1} (°C, cm^{-1})

Key No.	Treatment	C_0^{100}	k_0^{100}	Lit.
	Carbon Steels			
1	A 778°.......		0.59_8	(13, 19, 24)
	Hardened....	0.47_5		
	Normalized...		0.57_7	
3	As forged.....	0.47_3	0.59_8	(71, 73)
	Annealed.....	0.47_3		
4	Normalized...		0.46_0	(13)
5	Annealed.....		0.43_1	(19, 129)
	900° Q_w......	0.47_7	0.42_2	
7	As forged.....	0.47_7		(73, 129)
	Annealed.....	0.47_2	0.44_8	
	900° Q_w......		0.44_8	
13	As forged.....	0.48_5		(73)
	A 650° or N..	0.48_1		
14	As forged.....		0.35_6	(129)
	A 900°.......		0.39_3	
	900° Q_w......		0.31_0	
20	As forged.....	0.48_9		(73)
25	As forged.....		0.33_9	(129)
	A 900°.......		0.37_2	
	900° Q_w......		0.32_2	
31	As forged.....	0.49_4		(73)
	Normalized...	0.48_5		
	A 650°.......	0.47_7		
37	As forged.....		0.41_9	(24, 129)
	Annealed.....		0.43_9	
	900° Q_w......		0.31_5	
38	As forged.....	0.49_8		(19, 73)
	Annealed.....	0.48_9		
	Hardened....	0.48_9		
43	Annealed.....		0.43_1	(129)
46	As forged.....	0.49_8		(73)
	Normalized...	0.49_4		
	Annealed.....	0.48_9		
49	Annealed.....	0.39_3		(129)

TABLE 13.—THERMAL PROPERTIES.—(*Continued*)

Key No.	Treatment	C_0^{100}	k_0^{100}	Lit.
51	As forged.....		0.42_2	(129)
	Annealed.....		0.42_2	
53	As forged.....	0.50_6		(13, 19, 73)
	Normalized...		0.43_1	
	750° Q_w......	0.49_8		
57	As forged.....	0.51_0		(73)
	A 650° or N..	0.49_8		
60	As forged.....		0.39_3	(24, 129)
	Annealed.....		0.40_2	
	830° Q_w, 0°...		0.20_1	
62	Hardened....	0.51_0		(73)
64	As forged.....	0.51_0		(73, 129)
	Annealed.....	0.50_2	0.38_1	
66	As forged.....	0.51_5		(73)
	A 650°.......	0.49_8		
68	As forged.....	0.51_5		(24, 73)
	A 960°, C_f 24h		0.43_5	
	830° Q_w, 0°...		0.18_4	
69	Normalized...		0.41_0	(13, 19)
	Hardened....	0.51_5		
70	Normalized...		0.34_3	(13, 19)
	Hardened....	0.51_0		
73	Annealed.....		0.35_6	(129)
74	As forged.....	0.51_5		(73)
	A 650°.......	0.50_2		
78	As forged.....	0.51_0		(73, 129)
	Annealed.....	0.51_0	0.34_7	
	Cast Iron			
109	As cast.......	0.54_8		(73)
	A 650°/24 h..	0.54_4		
111	As cast.......		0.62_3	(85)
113	As cast.......	0.57_3		(73)
	A 670° { 5 min	0.56_0		
	10 min	0.55_2		
	60 min	0.48_5		
119	As cast.......	0.58_1		(73)
	A 650°/24 h..	0.57_3		
	Chromium Steels			
123	A 900°.......		0.41_4	(100)
	H 1100°......		0.37_2	

TABLE 13.—THERMAL PROPERTIES.—(*Continued*)

Key No.	Treatment	C_0^{100}	k_0^{100}	Lit.
129	A 900°.......		0.40_2	(100)
	H 1100°......		0.36_8	
140	A 900°.......		0.39_7	(100)
	H 1100°......		0.36_4	
141	W *CR* Q_w....	0.54_0		(19)
	C_a...........		0.38_9	
145	W *CR* Q_w....	0.54_0		(19)
146	A 900°.......		0.37_2	(100)
	H 1100°......		0.23_8	
153	A 900°.......		0.30_5	(100)
	H 1100°......		0.18_4	
169	W *CR* Q_w....	0.50_2		(19)
170	A 900°.......		0.21_8	(100)
	H 1100°......		0.16_3	
178	1000° Q_o.....		0.18_4	(71)
	Same, Tp 820° Q_w.........	0.48_1	0.19_7	
180	950° Q_o { 250° Q_w		0.16_7	(71)
	750° Q_w	0.49_4	0.19_2	
182	1000° Q_o.....		0.13_0	(71)
	Same, Tp 820° Q_w.........	0.48_9	0.18_0	
183	1000° Q_o.....	0.48_1	0.13_0	(71)
	Same, Tp 820° Q_w.........	0.50_6	0.15_1	
	Copper Steels			
230	Hardened....	0.53_5		(13, 19)
	Air cooled....		0.49_4	
236	Hardened....	0.53_5		(13, 19)
	Air cooled....		0.52_3	
237	Hardened....	0.53_1		(19)
239	Hardened....	0.48_9		(19)
	Nickel Chromium Steels			
266	A 718°.......		0.25_1	(24)
	Same, W 830° Q_w, 0°.......		0.22_2	
276	1000° Q_w.....		0.11_7	(71)
278	As received...	0.51_4	0.10_5	(20)

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(For key to the periodicals see end of volume)

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Mn-, Si-, AND Mn-Si-STEELS; Fe-Si-ALLOYS; AND EFFECT OF Mn AND Si ON CAST IRON

ROBERT A. HADFIELD

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TABLE 1.—TENSILE, HARDNESS, AND IMPACT TESTS ON ROLLED AND FORGED MN-STEELS*

Composition, hundredths of %: Mn	C	Si	P	S	Treatment, *v.* p. 392	10 × *UTS*	10 × {Y = *YP*, E = *EL*, P = *PL*}	10 × *El*†	10 × *RA*	Lit.‡
					C < 0.3 %					
39	8	0.5	1.0	3.4	F, A 750°/3 h C_z.....	346		365	720	(29)
48	8	0.8	0.7	1.6		358		360	720	(29)
50	12	0.8	2.7	3.0		386		330	620	(29)
58§	13	0.6	2.7	3.7		402		320	640	(29)
58§	14	0.9	2.6	3.5		436		300	610	(29)
60	8	0.6	2.6	4.3		367		350	700	(29)
69§	13	0.9	3.1	2.4		424		320	680	(29)
83§	20	3			F........................	528	339 E	315	457	(14, 17)
110§	<10	<21	<7	<4	R, A 860°‖..............	386¶	299 Y	435	797	(2)
129§	10	37	2	2	F, N 1000°..............	507	358 E	350	650	(1)
130	7.3				F........................	425	282 E	*IS* = 39.0**		(10)
170§	10.4				F........................	498	287 E	*IS* = 36.0**		(10)
210§	23.6				F........................	558	408 E	*IS* = 28.1**		(10)
313	<10	<21	<7	<4	R, A 860°‖..............	652¶	545 Y	250	632	(2)
410	<10	<21	<7	<4	R, A 860°‖..............	842¶	324 Y	250	424	(2)
540	15	3.7			F, WY Q_w..............	622		50	0	(13)
550	<10	<21	<7	<4	R, A 860°‖..............	1040¶	610 Y	285	381	(2)
560	27.6				F........................	720	720 E	*IS* = 3.05**		(10)
588	3	11	<3	<5	F, A 926°/15...........	808	458 P	13	13	(30)
					Same, W_2 955° Q_w††....	1008	617 P	121	420	
610	3.4				F........................	1183	843 E	*IS* = 3.05**		(10)
861	4	16	<3	<5	F, A 926°/15...........	1059	618 P	17	26	(30)
					Same, W_2 955° Q_w††....	1074	696 P	20	33	
887	81	22	<3	<5	F, A 870°/15, W_2 900° Q_w††..................	651	298 P	121	202	(30)
1050	<10	<21	<7	<4	R, A 860°‖..............	912¶	485 Y	10	0	(2)
1290	<10	<21	<7	<4	R, A 860°‖..............	884¶	312 Y	65	46	(2)
1290	15.6				F........................	650	299 E	*IS* = 12**		(10)
1570	<10	<21	<7	<4	F, A 860°‖..............	1004¶	596 Y	175	206	(2)
1635	5	38	<3	<5	F, A 927°..............	736	198 P	166	135	(30)
					Same, W_2 955° Q_w††....	840	239 P	400	495	
1985	<10	<21	<7	<4	R, A 860°‖..............	866	351 Y	300	335	(2)
3350	29.6				F........................	614	342 E	*IS* = 28.1**		(10)
					C, 0.3–0.6 %					
98	50	9.4	9.8	8	F, W 659° Q_w..........	753	471 E	152	502	(6)
v. also Figs. 1 and 2					F, W 700° Q_w..........	878	443 E		85	
230§	40	15			F........................	890		65	70	(14, 17)
358	45	5	<3	<5	F, A 870°/15...........	865	438 P	204	443	(30)
					Same, W_2 816° Q_o††.....	1104	954 P	170	466	

Table 1.—Tensile, Hardness, and Impact Tests on Rolled and Forged Mn-Steels.*—(*Continued*)

Composition, hundredths of %					Treatment, *v.* p. 392	10 × *UTS*	10 × {Y = *YP*, E = *EL*, P = *PL*}	10 × *El*†	10 × *RA*	Lit.‡
Mn	C	Si	P	S						
389	40	9			F	598		5		(14, 17)
872	48	8	<3	<5	F, A 870°/15	900	274 P	17	26	(30)
					Same, W_2 900° Q_w††	520	260 P	17	20	
1439	46	10	<3	<5	F, A 870°/15	710	219 P	163	190	(30)
					Same, W_2 900° Q_w††	770	219 P	183	226	
					C, 0.6–0.9%					
41	78	6	2	3	R, A 860°‖	672	425 Y	150	205	(3)
50	87.3				F	1150	595 E	*IS* = 3.05**		(10)
83	78	8	2	4	R, A 860°‖	778	548 Y	150	160	(3)
116	85	9	2	4	R, A 860°‖	832¶	406 Y	105	117	(2)
186	78	16	<3	<5	F, A 870°/15	906	378 P	108	135	(30)
					Same, W_2 788°†† ‡‡	1195	1014 P	142	333	
200	80.4				F	1054	791 E	*IS* = 3.05**		(10)
221	86	11	2	3	R, A 860°‖	901	476 Y	80	107	(3)
310	85	13	2	2	R, A 860°‖	939¶	622 Y	50	52	(2)
385	81	9	2	2	R, A 860°‖	753	533 Y	20	21	(3)
440	78	18	<3	<5	F, A 870°/15	980	417 P	54	66	(30)
					Same, W_2 788°†† ‡‡	1252	894 P	33	40	
498	87	18	2	2	R, A 860°‖	860¶	535 Y	20.	20	(2)
510	76.2				F	866	602 E			(9)
720	70				F	566	414 E	*IS* = 10**		(10)
937	61	30	7	7	F	514	394 E	55		(14, 17)
1229	85	37	9	6	F	619	440 E	35	80	(14, 17)
1511	82	19	5	3	R, A 860°‖	786¶	441 Y	5	7	(2)
					C > 0.9%					
300	93.4				F	1010	827 E	*IS* = 3.05**		(10)
462	120	31	<3	<5	F, A 870°/15	910	378 P	46	53	(30)
					Same, W_2 900° Q_w††	473	298 P	33	85	
868	127	19	<3	<5	F, A 870°/15	1234	676 P	13	13	(30)
					Same, W_2 900° Q_w††	677	318 P	79	141	
1007§	95	17	4	3	R, A 860°‖	665¶	474 Y	10	14	(2)
1121§	100	19	4	3	R, A 860°‖	703	547 Y	10	8	(3)
1200§	96				F	896	618 E	*IS* = 28.1**		(10)
1268§	94	14	<3	<5	F, A 870°/15	786	240 Y	17	27	(30)
					Same, W_2 900° Q_w††	1024	318 Y	471	392	
1338§	107	27	4	2	R, A 860°	730	438 Y	30	31	(3)
1522	150	14			F	693		10		(13)
					F, *WW* Q_w	701		120		
					F, *WW* C_a	622		10		
					Same	638		40		
1959	93	21	7	3	R, A 860°‖	822¶	389 Y	235	195	(2)

* *v. also* Tables 2–6.

† Dimensions of test pieces: (1, 2, 3) 2 in. × 0.564 in. diam.; (6) 8 in. × 0.5 in. diam.; (3, 10) not stated; (13) 2 in. × 0.798 in. diam.; (14, 17) 8 in. × 0.75 in. diam.; (29) 10 cm × 2 cm diam.; (30) 1.2 in. × 0.30 in.

‡ *See also* (16, 18, 19, 27, 34).

§ Steels of commercial importance.

‖ R, A 860°/36 h C 3 days.

¶ Brinell hardness number given in this table: (Treatment = 1000° Q_w).

Mn	C	*BHN*	Mn	C	*BHN*	Mn	C	*BHN*
110	<10	143	1290	<10	302	498	87	286
313	<10	430	1570	<10	192	1511	82	196
410	<10	418	1985	<10	235	1007	95	179
550	<10	418	1160	85	650	1959	93	192
1050	<10	444	310	85	600			

** Impact test on Fremont machine.

†† For 30 min.

‡‡ Q_o W_3 594°/30 C_a.

Table 2.—Effect of Cooling Medium on Properties of Forged Mn-Steel (14, 17)

Test pieces, 8 in. × ¾ in. diam.

Hundredths of %					F		F, $WY\ Q_w$		F, $WY\ Q_o$		F, $WY\ C_a$	
Mn	C	Si	P	S	10 × *UTS*	10 × *El*	10 × *UTS*	10 × *El*	10 × *UTS*	10 × *El*	10 × *UTS*	10 × *El*
695	52	37	8	7	400	15	365	16	296	16	332	23
722	47	44			432	16	387	16	392	31	421	47
790	50	28							466	70	447	78
937	61	30	7	7	514	55	613	148	602	148	594	156
1060	85	28			529	39	644	172	663	188	644	172
1401*	85	28			573	16	1057	444	865	266	755	141
915	100	42							665	172		
1011*	95	21			605	55			646	195	619	141
1260*	110	16			619	23	849	273	792	281	584	109
1281*	92	42			616	55	958	367	908	328	761	195
1998	190	32							359	Nil		
2169	210	46			567	86			525	109	531	117

Hundredths of %			F			F, $WY\ Q_w$			F, $WY\ C_a$		
Mn	C	Si	10 × *UTS*	10 × *EL*	10 × *El*	10 × *UTS*	10 × *EL*	10 × *El*	10 × *UTS*	10 × *EL*	10 × *El*
1448*	110	32	620	509	8	999	353	375	769	446	47
1506	124	16	776	514	23	954	351	312	739	381	23
1840	154	16	807	509	8	838	367	101	611	414	8
1855	183	26	669	559	4	875	399	54			
1910	160	26	811	558	8	922	558	46	641	451	8

* Steels of commercial importance.

Table 3.—Effect of Liquid Air Temperature on Forged Mn-Steels (13)

Hundredths of %			Treatment, *v.* p. 392	Tensile tests*			
				At *ca.* 20°C		At −182°C†	
Mn	C	Si		*UTS*	*El*	*UTS*	*El*
350	8	13	1102° C_a 777° C_f..	104	7.5	139	Nil
			Same, Q_{la}........	109	9		
540	15	3.7	1102° C_a 777° C_f....	104	Nil	96	Nil
1008	16	63	1048° Q_w..........	93	1	82	Nil
1527	15		1048° Q_w..........	61	5	72	2.5
223‡	41	7	1102° C_a 777° C_f....	80	17	106	2.5
381	78		1102° C_a 777° C_f....	104	10	118	Nil
468	36	10	Same, W_2 614° C_f...	117	10	129	Nil
700	100		1048° Q_w..........	66	15	84	Nil
1153	166		1048° Q_w..........	88	10	120	2.5
1264‡	123		994° Q_w..........	102	40	101	Nil
			1048° Q_w..........	88	30	96	2.5
			620° Q_{la}..........	88	1.3		
			831° Q_{la}..........	91	11		
			994° Q_{la}..........	104	38		
1522	150	14	1048° Q_w..........	93	25	101	2.5

Mn, 12.64; C, 1.23 (1048° Q_w)	
p, atm.	*BHN* at *ca.* 20°C
10	194
20	191
40	205
p, atm.	*BHN*† at −182°C
10	341
20	363
40	372

* Test bars, 2.00 in. × 0.180 in. diam.
† Tests carried out in liquid air.
‡ Steels of commercial importance.

Table 4.—Compression Tests on Forged Mn-Steels (17)*

Composition, hundredths of %					Treatment	EL_C	$-100\frac{\Delta l}{l_0}$†
Mn	C	Si	P	S			
937	61	31	7	7	F	39.5	20.10
1229	85	37	9	6	F, $WY\ Q_w$	53.5	17.05
1375	85	23	9	8	F, $WY\ Q_w$	70	16.65

* *v. also* (1, 18).
† Reduction in length due to applied stress of 157.5 kg/mm².

Table 5.—Tensile Properties and Hardness of Cast Mn-Steel (22)*

Treatments: α = G; β = G, A 900°/60; γ = G, A 900°/60 Q_w 15°.

No. and Trt		10 × *UTS*	10 × *YP*	10 × *El*	10 × *RA*	*BHN*
1	α..............	439	325	279	535	119
	β..............	400	304	315	700	113
	γ..............	554	302	196	610	147
2	α..............	457	335	292	625	115
	β..............	405	307	305	668	116
	γ..............	580	324	192	620	165
3†	α..............	466	350	294	639	115
	β..............	418	312	303	700	115
	γ..............	592	342	160	622	154
4†	α..............	454	347	279	659	119
	β..............	421	317	303	701	118
	γ..............	594	350	141	561	157
5†	α..............	479	362	287	642	123
	β..............	430	320	308	718	123
	γ..............	680	350	155	530	179
6†	α..............	503	383	279	681	132
	β..............	457	328	302	726	132
	γ..............	758	443	152	482	230
7†	α..............	503	380	280	677	134
	β..............	463	335	298	703	135
	γ..............	783	465	163	478	237
8†	α..............	580	408	259	547	156
	β..............	520	340	274	723	159
	γ..............	1090	603	90	446	274
9†	α..............	597	411	260	468	162
	β..............	551	347	262	667	165
	γ..............	1106	627	67	417	289
10	α..............	652	428	212	434	197
	β..............	647	351	188	606	198
	γ..............	1158	639	49	266	326
11	α..............	725	446	188	394	211
	β..............	761	367	154	531	218
	γ..............	1171	649	31	189	

No.	Thousandths of %				
	Mn	C	Si	P	S
1	285	109	319	63	46
2	440	125	286	67	50
3†	675	126	303	67	46
4†	785	99	311	40	52
5†	1020	98	316	41	49
6†	1270	100	313	99	45
7†	1315	101	303	102	47
8†	1765	102	309	103	[illegible]
9†	1835	99	324	108	[illegible]
10	2230	90	301	102	[illegible]
11	2470	92	294	110	[illegible]

* Specimens 20 cm × 2 cm diam.
† Steels of commercial importance.

Table 6.—Transverse Tests on Cast Mn-Steel* (17); *cf.* (18)

Composition, hundredths of %					*BMR*
Mn	C	Si	P	S	
32	15	1	9	11	49
76	23	4	9	7	84
231	40	15	7	7	122

* Test bars 2⅝ in. square, loaded at center, bearings 2 ft. apart.

TABLE 6.—TRANSVERSE TESTS ON CAST MN-STEEL* ([17]); *cf.* ([18]) (*Continued*)

Composition, hundredths of %					*BMR*
Mn	C	Si	P	S	
389	35	9	6	7	18
643	34	30	11	11	30
695	52	37	8	7	54
830	62	35	10	4	71
1476	115	25	12	7	72
1762	140	91	10	6	92.5
2345	215	65	9	2	106.5

* Test bars 2⅝ in. square, loaded at center, bearings 2 ft. apart.

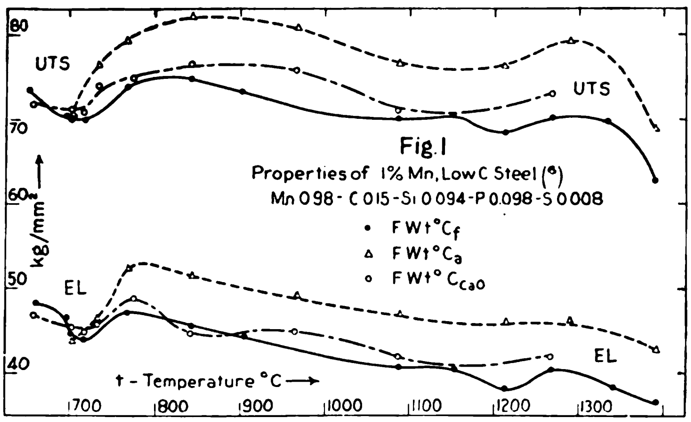

Fig. 1
Properties of 1% Mn, Low C Steel ([6])
Mn 0.98 - C 0.15 - Si 0.094 - P 0.098 - S 0.008

TABLE 7.—TENSILE PROPERTIES OF FE*-SI-ALLOYS ([38]); *cf.* ([31])

% Si \ Trt	As forged		A_v 970° C 30°/h	
	UTS	*YP*	*UTS*	*YP*
0.001	31.5	25.2		
.001	32.8	31.2	25.4	11.5
.001	28.7	26.8		
.010	31.8	29.5	24.6	11.3
.048	32.9	30.1	24.6	14.2
.068	30.9	25.8	24.6	14.3
.091	30.7	25.0	24.9	10.1
.148	31.7	27.1	24.7	11.2
.205	35.0	29.9	27.3	17.6
.230	33.4	29.0		
.242			26.9	12.8
.309			28.4	15.3
.400			29.6	18.3
.472			30.1	12.1
.563	35.9	28.7		
.673	40.8		31.8	18.7
.698			30.2	16.2
.822	39.2	31.8	31.8	18.4
1.71	53.7	47.9	38.1	25.2
1.741			38.8	32.1
2.73			47.7	34.8
3.40	60.6	52.5	54.5	40.2
3.55	69.8	58.6		
4.39	73.9	66.2	59.7†	59.7†
4.44			64.5	51.2
4.92	35.3	35.3		
6.57	3.6	3.6	9.1	9.1

* Pure electrolytic Fe, melted *in vacuo*, % C = *ca.* 0.01. Test pieces *ca.* 2.5 in. × 0.5 in. diam.

† AN_2 1030°.

TABLE 8.—SPECIFIC GRAVITY OF PURE FE-SI-ALLOYS ([28]); *v. also* ([9, 15, 21])

Prepared from pure soft wrought Fe and pure Fe-Si, only very small amounts of impurities present. Determination by pycnometer.

Si, %	d_4^{20}	Si, %	d_4^{20}	Si, %	d_4^{20}
0.2	7.883	24.8	6.432	65.9	3.367
2.0	7.784	27.2	6.248	79.4	2.787
7.5	7.352	29.3	6.198	93.4	2.363
15.0	7.032	40.2	5.378	95.0	2.322
20.0	6.696	46.8	4.876	100.0	2.309
21.9	6.546	51.8	4.406		

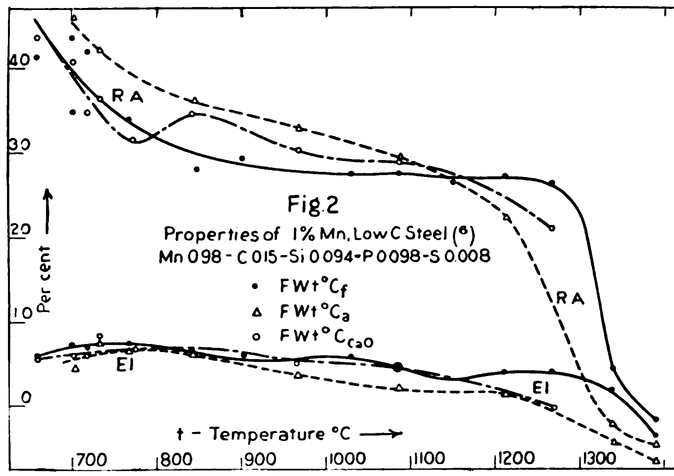

Fig. 2
Properties of 1% Mn, Low C Steel ([6])
Mn 0.98 - C 0.15 - Si 0.094 - P 0.098 - S 0.008

TABLE 9.—TENSILE PROPERTIES AND HARDNESS OF ROLLED AND FORGED SI-STEELS

v. also Tables 10–12

Thousandths of % Si-C-Mn-P-S	Treatment, *v.* p. 392	Tensile tests 10 × *UTS*	10 × *EL*	10 × *El*	10 × *RA*	Hardness T = *TSH* B = *BHN*	Lit.*
24-44-36-14-30	R, N 1000° C_a	356	183	430	670		([4, 5])
	R, A 950°†	356	313	470	715		
	F	386	317	402	683		
180-140-140-50-80	F	520	346	301	545		([15])
200-140-140-51-80	F, A (180)¶	394	239	376	607	20 T	
409-208-717-117-61	F	602	452			153 B	([12])
	F, W 850° Q_w	838	509			223 B	
433-878-730-57-13	F	1152	625			302 B	([12])
	F, W 850° Q_w	1219	976			555 B	
700-180-210	F	536	394	295	545		([15])
730-180-210	F, A (180)¶	465	299	340	527	20 T	
870-180-210	F, A (180)¶	449	299	255	426		([15])
932-209-Tr.-24-20	F	586	377			146 B	([12])
	F, W 850° Q_w	739	416			262 B	
	F, W 950°/4 h.	473	334				
1020-38-79-19-38	R, N 1000° C_a	482	334	355	668		([4, 5])
	R, A 950°†	429	317	403	763		
	F	485	427	368	674		
1156-835-570-21-17	F	1040	625			293 B	([12])
	F, W 850° Q_w	1414	1414			555 B	
1600-190-280‡	F	591	441	311	506		([15])
1520-190-280‡	F, A (180)¶	520	394	351	545	24 T	
1600-117-275-32-12‡	F	566	452			159 B	([12])
	F, W 850° Q_w	731	640			196 B	
	F, W 950°/4 h.	452	303				
	F, W 950°/8 d.	534	433				
1940-80-110-20-20‡	F, N *ca.* 1000°‖	500	321	360	624	§	([1])
2090-968-407-32-22	F	1054	769			277 B	([12])
	F, W 850° Q_w	1328	1328			578 B	
2110-200-250-40-60‡	F	622	488	185	280		([15])
2130-200-250-40-60‡	F, A (180)¶	536	402	365	600	24 T	

Table 9.—Tensile Properties and Hardness of Rolled and Forged Si-Steels.—(*Continued*)

Thousandths of % Si-C-Mn-P-S	Treatment, v. p. 392	Tensile tests 10 × *UTS*	10 × *EL*	10 × *El*	10 × *RA*	Hardness T = *TSH* B = *BHN*	Lit.*
2125-(C-Mn, etc. 176)	R, N 1000° C_a	514	337	245	288		(4, 5)
	R, A 950°†	473	312	398	659		
	F	558	440	280	454		
2690-200-250	F	670	504	176	244		(15)
2670-200-250	F, A (180)¶ **	504	378	61	66	26 T	
2903-38-61-18-41	R, N 1000° C_a	493	432	42	42		(4, 5)
2903-38-79-19-38	R, A 950°†	534	345	355	600		
	F	586	462	155	146		
3390-210-290‡	F	748	552	111	142		(15)
3360-210-290‡	F, A (45)¶	614	473	89	93	30 T	
4026-(C, Mn, etc. 242)	R, N 1000° C_a	575		Nil	Nil		(4, 5)
	R, A 950°†	687		22	28		
	F	659		Nil	Nil		
4180-250-360‡	F	772	709	0	2		(15)
4230-250-360‡	F, A (15)¶	599		6.4	9.8	33 T	
4900-260-290-40-60	F	756		3	7		(15)
4800-260-290-40-60	F, A (0)¶	394	394	4		36 T	
4885-40-72-21-27	R, N 1000° C	572		Nil	Nil		(4, 5)
	R, A 950°†	654		Nil	Nil		
	F	657		Nil	Nil		
5120-277-380-34-9	F	618	526			248 B	(12)
	F, W 850° Q_w	627	528			311 B	
5530-260-290	F, A	394	394	5	Nil		(13)
5998-(C, Mn, etc. 249)	R, N 1000° C_a	254		Nil	Nil		(4, 5)
	R, A 950°†	419		Nil	Nil		
	F	315		Nil	Nil		
7470-(-)-210-19-11	R, N 1000° C_a	326		Nil	Nil		(4, 5)
	R, A 950°†	332		Nil	Nil		
	F	377		Nil	Nil		

* Dimensions of test pieces: (1) 2 in. × 0.564 in. diam.; (4, 5) 2 in. × 0.580 in. diam.; (12) not stated; (13, 15) 2 in. × 0.798 in. diam.; *v. also* (32, 34, 35).

† Annealed for 40 h and cooled over 170 h.

‡ Steels of commercial importance.

§ $d_4^{20} = 7.733$.

‖ Bar 5 in. long × 3/8 in. diam. bent 180°, radius = 5/16 in.

¶ (*x*) = bars 1/2 in. × 1/4 in. cross section bent cold through *x*°, radius = 3/8 in.

** Broke at end in bend test.

Table 10.—Effect of Liquid Air Temperature on Forged Si-Steel (13)

Tensile tests* (bars 2.00 in. × 0.18 in. diam.)

% composition Si	C	Mn	*ca.* 20 *UTS*	*El*	−182 *UTS*	*El*
2.28	0.67	0.50	97.6	15	97.6	0
2.67	0.20	0.25	67.7	17	92.9	0
2.77	0.34		81.9	17	92.9	0
3.03	0.07	0.064	61.4	22	67.7	0
3.89	0.11	0.02	69.3	2.5	39.4	0

* Treatment: W 1102° C_a W_2 777° C_f.

Brinell hardness number

No. I: Si, 2.28; C, 0.67; Mn, 0.5.
No. II: Si, 3.05; C, 0.11; Mn, 0.08.

p, atm. \ No.	I At *ca.* 20°C	I At −182°C	II At *ca.* 20°C	II At −182°C
10	305	374	187	328
20	299	396	197	305
40	307	401	206	343

Table 11.—Compression Tests on Forged Si-Steels (15); *v. also* (1)

CS \ % composition	Si, 0.79; Mn, 0.21; C, 0.18 *l*, in.*	*d*, in.†	Si, 2.67; Mn, 0.25; C, 0.20 *l*, in.*	*d*, in.†
0	1.0	0.798	1.009	0.798
15.8	0.996	0.799	1.009	0.798
31.5	0.992	0.800	1.008	0.800
47.3	0.947	0.822	0.992	0.808
63.0	0.853	0.890		
78.8	0.814	0.894	0.901	0.850
94.5	0.731	0.950		
110.3	0.658	1.002		
126.0	0.598	1.056		
141.8	0.547	1.115		
157.5	0.503	1.153	0.622	1.035

CS \ % composition	Si, 3.46; Mn, 0.29; C, 0.21 *l*, in.*	*d*, in.†	Si, 4.49; Mn, 0.36; C, 0.25 *l*, in.*	*d*, in.†
0	1.009	0.799	1.008	0.799
15.8	1.009	0.799	1.008	0.799
31.5	1.009	0.799	1.008	0.799
47.3	1.005	0.800	1.005	0.800
63.0			0.990	0.806
157.5	0.646	1.012	0.683	1.003

* *l* = length. † *d* = diameter.

Table 12.—Properties of Cast Si-Steels (25)

Treatments: α = G; β = G, A 1100°/10 h; $\gamma = \beta$, C_s 900-1000° Q_w; δ = G, A 900°/1 h Q_w.

No. and Trt		10 × *UTS*	10 × *YP*	10 × *El**	10 × *RA*	*BHN*†
1	α	443	320	300	575	130
	β	392	269	275	675	118
	γ	524	345	110	570	160
	δ	573	365	175	652	162
2	α	430	335	295	670	131
	β	398	287	273	695	122
	γ	554	354	106	540	200
	δ	625	450	156	576	205
3	α	457	346	283	580	144
	β	432	318	260	687	126
	γ	616	384	100	470	203
	δ	679	450	156	576	205
4	α	485	378	282	550	150
	β	443	318	215	645	136
	γ	660	400	97	331	216
	δ	699	450	148	550	210
5	α	551	420	277	450	168
	β	513	324	190	560	152
	γ	756	406	75	162	258
	δ	724	452	132	440	230
6‡	α	562	446	262	400	180
	β	524	336	185	500	174
	γ	814	524	22	39	269
	δ	776	455	120	335	250
7‡	α	587	469	232	395	182
	β	545	335	182	490	176
	γ	820	540	22	32	278
	δ	820	457	112	320	258

TABLE 12.—PROPERTIES OF CAST SI-STEELS ([25]).—(*Continued*)

No.	Thousandths of % Si	C	Mn	P	S
1	240	120	410	33	64
2	370	100	300	41	49
3	670	110	230	44	44
4	950	110	360	40	43
5	1250	150	500	43	42
6‡	1730	150	560	45	40
7‡	2350	120	290	40	58

No.	1	2	3	4	5	6	7
d_4^{20}§	7.861	7.853	7.835	7.810	7.774	7.733	7.702

* Test pieces 20 cm × 2 cm diam.
† 10 mm ball, 2000 kg load.
‡ Steels of commercial importance.
§ As cast (G).

TABLE 13.—PROPERTIES OF FORGED SI-MN-STEELS ([11])

Composition, thousandths of % C	Mn	Si	P	S	Trt	BHN*	10 × UTS	10 × EL	10 × El†	10 × RA	IS‡
104	1 728	457	32	8	A§	101	476	274	145	305	32
					N 900°	107	498	287	175	582	36
					850° Qw	234	655	444	35	396	16
210	2 072	1 352	19	8	A§	126	583	448	130	342	4
					N 900°	153	602	465	140	572	6
					850° Qw	269	1 155	1 155	0	0	0
224	14 400	911	24	Tr.	A§	202	747	227	120	172	30
					N 900°	212	791	233	100	147	27
					850° Qw	196	706	205	150	186	30
237	2 150	781	32	10	A§	107	559	405	147	305	18
					N 900°	107	558	407	155	572	28
					850° Qw	248	1 070	1 070	10	50	4
240	14 760	1 880	29	Tr.	A§	269	1 032	695	0	0	0
					N 900°	248	945	498	50	60	7
					850° Qw	300	1 078	925	0	0	1
490	11 940	2 310	32	Tr.	A§	196	698	443	190	146	19
					N 900°	202	799	492	100	125	15
520	11 840	432	17	Tr.	A§	153	704	405	200	248	27
					N 900°	196	725	482	190	223	25
565	450	960	37	Tr.	A§	244	725	528	80	60	6
					N 900°	248	765	503	120	145	8
572	12 007	1 210	28	15	A§	153	717	421	190	175	22
					N 900°	202	758	465	150	146	20
620	525	1 840	25	12	A§	269	805	539	60	53	2
					N 900°	293	832	544	100	87	6

Thousandths of % C	Mn	Si	P	S	Treatment ([26]); *cf.* ([17])	10 × UTS	10 × EL	10 × USS‖	10 × EL§
700	7 200	745	21	10	A 850°/180	566	414	490	142
762	5 112	1 118	11	13	A 850°/180	866	602	608	460
840	1 031	573	15	24	A 850°/180	1 183	685	454	340
873	461	1 351	24	20	A 850°/180	1 150	595	430	298
922	10 080	721	16	13	A 850°/180	978	482	490	139
930	1 972	1 028	11	18	A 850°/180	1 054	791	460	309
934	3 084	1 446	10	15	A 850°/180	1 010	829	485	334
960	12 096	876	13	11	A 850°/180	896	618	482	156

* 10 mm ball, 3000 kg load.
† Tensile specimens, 10 cm × 1.38 cm diam.
‡ Guillery machine, Fremont test piece 8 × 10 × 10 mm.
§ Forged and annealed at 950° and 1200°.
‖ Fremont machine, test pieces 6 mm × 8 mm cross section.

TABLE 14.—EFFECT OF MN CONTENT ON TENSILE STRENGTH AND ELONGATION OF MALLEABLE CAST IRON ([24])

% composition (before annealing) Mn	C	Si	P	S	UTS*	El*	Annealing time, hr†
0.13	3.06	0.45	0.071	0.041	41.3	3.5	95
					36.1	5.0	130
					32.5	13.0	260
0.26	2.60	0.41	0.078	0.042	45.1	4.5	95
					36.9	6.0	130
					33.6	14.5	260
0.38	3.18	0.32	0.089	0.042	44.6	3.0	95
					37.2	4.8	130
					33.2	14.0	260
0.66	2.58	0.44	0.075	0.044	44.8	3.0	95
					40.8	6.5	130
					34.7	15.5	260
0.78	3.11	0.44	0.078	0.054	46.5	2.5	95
					40.5	5.5	130
					34.5	13.5	260
0.80	2.76	0.47	0.068	0.044	46.9	2.7	95
					41.6	6.5	130
					34.7	15.0	260
0.94	2.76	0.39	0.068	0.050	48.4	3.0	95
					42.4	6.0	130
					35.6	13.5	260
1.05	2.58	0.51	0.056	0.054	50.9	2.3	95
					45.1	6.0	130
					38.0	14.5	260
1.12	2.90	0.41	0.087	0.038	50.4	2.0	95
					45.7	5.0	130
					38.4	15.5	260
1.32	2.82	0.33	0.072	0.038	48.5	1.5	95
					46.6	3.0	130
					40.7	16.0	260
1.52	2.99	0.45	0.076	0.044	53.1	2.0	95
					50.3	3.0	130
					43.2	14.3	260
1.74	3.30	0.36	0.097	0.040	52.1	1.5	95
					48.1	2.0	130
					43.2	11.0	260

* Test pieces 100 mm × 12 mm diam.
† Annealed with forge, scale at 980°C.

TABLE 15.—EFFECT OF SI CONTENT ON GENERAL MECHANICAL PROPERTIES OF MALLEABLE CAST IRON ([23])

Composition, hundredths of % Si	C	Mn	P	S	$10^3 d_4^{20}$ before annealing	Annealing time, hr*	$10^3 d_4^{20}$ after annealing	10 × UTS	10 × El†	10 × RA	10 × IS‡	BHN§
17	325	11	6.5	5.2	Porous	95	7786	398	40		24	107
						130		378	100	240		
						175	7761	362	108	260	40	90
						225		350	184	370	80	92
						260	7770	328	191	415	105	84
23	332	12	6.1	5.4	7745	95	7785	402	39		24	120
						130		377	94	225		99
						175	7767	364	99	245	36	96
						225		348	161	350	75	
						260	7766	331	180	380	98	87
30	309	12	6.0	5.0	7746	95	7699	444	40		25	123
						130		372	94	220		101
						175	7683	364	98	240	36	96
						225		350	162	345	72	94
						260	7676	336	174	355	79	88

TABLE 15.—EFFECT OF SI CONTENT ON GENERAL MECHANICAL PROPERTIES OF MALLEABLE CAST IRON ([23]).—(*Continued*)

Composition, hundredths of %: Si	C	Mn	P	S	$10^4 d_4^{20}$ before annealing	Annealing time, hr*	$10^4 d_4^{20}$ after annealing	10 × *UTS*	10 × *El*†	10 × *RA*	10 × *IS*‡	*BHN*§
38	306	12	5.7	4.9	7742	95	7633	425	31		24	125
						130		372	80	210		106
						175	7614	366	88	225	36	102
						225		353	140	300	72	94
						260	7594	332	161	340	84	91
44	316	12	6.2	5.8	7730	95	7625	436	31		26	127
						130		388	71	185		107
						175	7607	373	84	190	35	104
						225		351	140	260	69	99
						260	7607	342	161	315	72	92
50	297	12	6.6	6.7	7727	95	7632	443	31		22	128
						130		394	72	190		111
						175	7606	377	79	190	33	104
						225		358	139	265	65	100
						260	7602	343	157	310	69	94
55	312	12	6.2	6.8	7709	95	7601	413	28		22	131
						130		377	58	130		113
						175	7566	372	66	145	33	104
						225		353	126	210	58	101
						260	7546	342	148	250	64	96
58	311	13	6.1	5.9	7716	95	7484	425	29		21	129
						130		385	58	130		112
						175	7502	369	68	150	33	129
						225		355	123	240	55	102
						260	7460	344	149	270	58	96
67	327	12	6.8	5.6	7705	95	7440	432	25		22	133
						130		373	47	115		113
						175	7384	366	57	125	32	133
						225		344	123	220	46	97
						260	7357	339	138	240	53	93
71	316	13	5.7	6.4	7701	95	7473	407	22		19	136
						130		378	47	130		117
						175	7497	377	62	135	33	111
						225		351	118	230	47	100
						260	7435	339	134	245	57	99
75	325	14	5.6	5.7	7700	95	7441	424	25		22	133
						130		377	45	125		117
						175	7463	373	58	135	33	112
						225		355	110	230	47	101
						260	7396	342	128	235	55	101
81	317	13	6.8	5.4	7689	95	7343	432	20		19	137
						130		364	39			110
						175	7268	366	57	135	33	108
						225		353	108	190	46	99
						260	7299	339	123	213	51	96
81	324	13	5.8	6.0	7686	95	7364	416	18		22	139
						130		372	40	110		
						175	7386	369	52	130		
						225		353	111	210		100
						260	7328	339	126	215		100
83	332	14	5.3	6.7	7687	95	7384	409	22		21	130
						130		361	39	105		111
						175	7356	361	56	125	32	112
						225		350	108	190	47	101
						260	7328	337	127	220	48	98
94	334	14	5.6	5.6	7682	95	7353	419	22		19	138
						130		374	39	100		113
						175	7339	376	51	105	33	116
						225		355	110	200	47	103
						260	7299	344	123	220	71	99
105	324	14	6.0	5.7	7675	95	7291	429	22		19	133
						130		373	36	80		114
						175	7267	373	50	95	35	116
						225		348	100	165	47	104
						260	7257	336	108	170	50	101
108	319	14	6.6	5.2	7664	95	7248	425	25		21	132
						130		356	33	50		111
						175	7190	350	45	90	33	107
						225		344	96		43	103
						260		317	98	130	46	98

* Annealed with forge, scale temperature = 980°C.

† Test pieces 100 mm × 12 mm diam.

‡ Small Charpy machine (25 kg-m max. energy), specimens 80 × 10 × 10 mm; impact length 60 mm notch, 2 mm deep × 3 mm wide.

§ 10 mm ball, 1000 kg load.

TABLE 16.—EFFECT OF MN ON PROPERTIES OF CAST IRON

Composition, hundredths of %: Mn	C: Graphite	C: Combined	C: Total	Si	P	S	*UTS**	*BMR**	*BHN*†	*ScH*	Lit.
Graphite, <1.4 %											
35	109	213	322	82			24.4	49.2		58	(7)
200	107	201	308	103			25.8	46.8		65.5	(7)
Graphite, 1.4–1.8 %											
1.6	173	106	279	224	2.7	1.6	15.6	28.4		45	(7)
9.3	156	116	272	157	3.5	0.3	26.0	45.8	183		(37)
16	169	78	247	150	2.2	0.6	25.8	44.6	178		(37)
Graphite, 1.8–2.2 %											
1.4	215	113	328	100	9.0		20.0	34.7		47	(7)
4	210	92	302	162	9.3	1.5	15.9	33.7		43	(7)
23	183	138	321	137	6.2	1.0	25.7	43.2	188		(37)
56	194	69	263	155	2.9	0.5	33.1	53.4	215		(37)
71	215	65	280	153	3.1	0.3	32.8	58.0	213		(37)
79	195	79	274	171	4.1	0.6	32.5	58.2	214		(37)
93	212	78	290	157	3.0	0.3	32.0	60.1	225		(37)
96	215	64	279	154	2.9	0.7	33.1	59.6	221		(37)
171	210	88	298	149	6.2	1.0	29.3	47.3	240		(37)
Graphite, 2.2–2.6 %											
5	225	105	330	100			20.9	45.4		50	(7)
17	225	98	323	155	3.8	1.0	21.7	38.3	175		(37)
31	238	74	312	176	6.1	1.0	32.0	50.6	176		(37)
49	259	66	325	157	3.4	1.4	26.8	48.5	175		(37)
55	243	71	314	130	6.3	0.8	32.5	53.6	180		(37)
65	240	58	298	157	7.5	0.9	35.0	60.2	200		(37)
78	252	62	314	148	3.6	1.0	34.2	59.4	203		(37)
80	236	65	301	145	6.4	1.3	34.8	60.2	202		(37)
84.6	233	82	315	102			26.2	43.8		51.5	(7)
98	230	77	307	143	6.1	0.8	34.5	61.0	209		(37)
106	258	80	338	160	3.3	0.6	26.8	48.0	187		(37)
120	228	80	308	139	6.4	1.4	35.6	62.4	215		(37)
134	225	72	297	155	2.6	0.5	32.0	57.1	217		(37)
141	233	78	311	145	5.7	1.1	36.2	56.6	222		(37)
155	222	70	292	150	2.9	0.4	26.6	52.5	227		(37)
193	259	81	340	160	3.0	0.9	22.8	45.1	197		(37)
196	234	69	303	242			24.4	40.5		43	(7)
222	242	78	320	169			28.7	40.0		42.5	(7)
Graphite, 2.6–3.0 %											
37	263	61	324	150	3.8	0.5	23.3	46.2	173		(37)
54	289	30	319	152	2.7		23.5	34.0		31	(7)
61.1	283	22	305	225			19.1	29.5		31	(7)
63	276	54	330	166	3.0	1.2	26.2	47.3	173		(37)
90	270	56	326	162	3.3	1.0	27.7	47.7	184		(7)
102.3	264	47	311	229			24.4	34.8		38	(7)
103	261	43	304	150			23.8	38.4		40	(7)
124	260	67	327	157	3.8	1.2	27.6	47.5	190		(37)
146	271	73	344	155	3.4	1.0	27.3	48.7	188		(37)
173	261	83	344	159	3.8	1.1	28.1	46.9	191		(37)
Graphite, >3.0 %											
32	302	84	386	156	4.1	1.1	12.8	26.8	127		(37)
52	312	91	403	134	3.0	1.0	13.5	28.2	132		(37)
83	310	77	387	165	3.3	1.4	12.4	26.9	126		(37)
100	310	55	365	182	3.0	0.9	13.1	27.3	125		(37)
136	344	59	403	170	2.9	0.9	12.4	26.0	128		(37)
148	312	94	406	177	3.8	1.2	13.2	28.0	132		(37)
172	329	63	392	185	3.6	0.8	13.1	30.4	137		(37)
188	338	36	374	188	3.6	1.4	12.8	29.5	140		(37)
209	335	51	386	179	2.5	1.4	14.8	30.1	146		(37)
246	328	57	385	185	3.0	1.0	15.0	32.8	158		(37)

* Test pieces: Tensile, 6 in. × ¾ in. diam.; bending, 15 × 1 in. sq., tested on 12 in. span ([7]). Tensile, 10 cm × 2 cm diam.; bending, 60 cm × 3 cm diam. ([37]).

† 10 mm ball, 3000 kg load.

TABLE 17.—EFFECT OF MN CONTENT ON HARDNESS OF CAST IRON ([8])

White cast iron

% composition			ScH
Mn	Si	C	
0.03	0.040	3.15	58
1.48		3.28	60
2.82		3.19	65
4.40		3.14	70
5.40	0.083	3.45	73
6.30		3.43	80
7.20	0.081	3.39	59
9.12		3.45	58
10.67	0.072	3.46	54
12.35		3.50	52
13.50		3.49	58
16.00		3.80	67
16.20	0.100	3.45	64
18.65		3.91	60
23.30	0.120	3.85	70
30.50	0.173	3.95	70
34.10	0.156	3.85	71
38.55	0.155	3.93	72

Gray cast iron

% composition					ScH
Mn	C			Si	
	Total	Graphite	Combined		
0.55	3.66	2.87	0.79	2.45	20
1.00	3.70	3.39	0.31	2.46	37
1.61	3.63	3.16	0.47	2.35	40
2.23	3.60	3.25	0.35	2.35	38
2.65	3.60	3.33	0.27	2.39	33
3.45	3.70	3.12	0.58	2.48	42
4.19	3.80	2.94	0.86	2.44	53
5.15	3.12	2.69	0.43	2.40	55
5.83	3.40	2.65	0.75	2.34	56
6.62	3.24	2.60	0.64	2.40	58
8.35	3.85	2.15	1.70	2.38	63
9.89	3.83	2.10	1.73	2.45	66
10.30	3.95	1.98	1.97	2.41	67
11.15	4.00	1.85	2.15	2.48	65
17.57	4.25	1.14	3.11	2.54	87

TABLE 18.—EFFECT OF SI CONTENT ON CAST IRON

C, 1.8 to 2.2% ([33])

Composition, hundredths of %						$10^3 d_4^{20}$		E/10	TSH	UTS	UCS
Si	C		Mn	P	S	Cylinders	Turnings				
	Total	Graphite									
19	198	38	14	32	5	7560	7719	1814	72	15.9	118.6
45	200	10	21	33	5	7510	7670	2017	52	19.4	144.0
96	209	24	26	33	4	7641	7630	2192	42	20.0	144.0
196	218	162	60	28	3	7518	7350	1657	22	24.7	96.6
251	187	119	75	26	5	7422	7388	1791	22	23.0	121.6
296	223	143	70	34	4	7258	7279	1487	22	19.2	90.6
392	201	181	84	33	3	7183	7218	1100	27	17.8	75.1
474	203	166	95	30	5	7167	7170	1316	32	16.1	72.8
733	186	148	136	29	3	7128	7138	1036	42	8.3	78.1
980	181	112	195	21	4	6978	6924	980	57	7.6	53.7

Test bars 16 in. × 1⅛ in. diam.; cast upright, cooled in molds, tested with skin on.

TABLE 18.—EFFECT OF SI CONTENT ON CAST IRON.—(*Continued*)

C, 2.8 to 3.2% ([7])

Composition, hundredths of %						ScH	UTS*	BMR†
Si	C		Mn	P	S			
	Total	Graphite						
40	322	3		1.8	1.1	57	20.5	41.8
50	312	25				56.5	21.6	41.3
80	304	177			1.3	58	15.9	35.9
100	328	215	1.4	9		47	20.0	34.7
111	280	161				49	14.2	31.2
131	305	195			1.1	47	14.2	33.4
162	302	210	4	9.3	1.5	43	15.9	33.7
203	288	180	2			40.5	22.5	32.6
224	279	173	1.6	2.7	1.6	45	15.6	28.4

* 6 in. × ¾ in. diam.
† 15 in. × 1 in. sq., 12 in. between supports.

C, 2.9 to 3.25%; Mn, < 0.2%; P, < 0.05%; S, < 0.05% ([20])

Hundredths of %			UTS	Hundredths of %			UTS
Si	C			Si	C		
	Total	Graphite			Total	Graphite	
53	290	Tr.	35.9	196	323	268	23.5
63	290	Tr.	22.8	197	297	147	19.5
66	290	Tr.	21.1	205	312	250	23.6
88	290	Tr.	27.4	207	325	275	13.4
99	290	Tr.	28.5	219	325	275	24.6
110	300	Tr.	25.2	231	310	255	13.2
143	298	28	17.6	236	329	280	15.4
151	300	Tr.	18.3	241	313	240	22.7
168	295	65	18.0	250	305	230	20.6
171	300	Tr.	14.8	250	325	285	14.3
172	307	247	20.0	267	290	250	16.7
173	300	10	18.9	282	306	255	12.9
180	302	11	17.3	294	307	255	12.9
180	315	260	16.9	305	307	260	13.7
195	298	120	30.9				

C, 2.56% to 4.05%* ([36])

Hundredths of %			BHN†	UTS‡	BMR§
Si	C				
	Total	Graphite			
54‖	405	229	166	12.8	29.9
80	340	185	206	20.2	40.6
85	319	177	211	21.3	46.5
95	395	263	116	7.2	19.8
118	290	125	244	29.9	53.4
122	322	172	216	23.5	49.0
130	336	228	187	16.2	35.8
137¶	399	260	114	7.7	18.0
155	286	146	236	24.7	45.8
168	342	196	201	18.6	35.1
178	323	199	202	20.3	43.0
183	397	259	111	8.2	18.4
217	340	214	183	15.1	34.0
225	256	145	246	23.5	53.4
225**	320	281	124	14.2	28.4
241	290	228	161	19.5	36.7
282††	263	159	235	20.5	42.5
323‡‡	263	236	130	18.0	35.3

* Mn, P, S content low except where noted.
† 10 mm ball, 3000 kg load.
‡ 10 cm × 2 cm diam.
§ 60 cm × 3 cm diam.
‖ Mn, 17; P, 2; S, 1.6.
¶ Mn, 12; P, 2.7; S, 1.1.
** Mn, 12; P, 4.5; S, 1.
†† Mn, 12; P, 6.3; S, 0.7.
‡‡ Mn, 11; P, 7; S, 0.7 (hundredths of %).

TABLE 19.—EFFECT OF CASTING TEMPERATURE AND ANNEALING ON CAST IRONS OF DIFFERENT Si CONTENT (Mn, <0.2%; P, <0.03%; S, < 0.04%) (20)

Si (Hundredths of %)	C Total (Hundredths of %)	C Graphite (Hundredths of %)	$t_g : t_a$, °C*	UTS
129	325	Tr.	1250	19.4
	328	321	1250:1000	21.4
	325	Tr.	1403	21.1
	326	320	1403:1000	31.0
152	326	26	1201	11.8
	326	16	1300	17.0
	326	10	1403	18.6
	327	320	1300:1000	19.4
	331	323	1403:1000	22.1
170	323	223	1180	17.8
	333	325	1180:1000	16.1
	329	219	1250	16.9
	327	321	1250:1000	12.6
	330	180	1403	16.9
	330	324	1403:1000	17.8
200	331	251	1154	13.2
	332	261	1215	14.5
	332	326	1215:1000	15.8
	330	250	1366	14.3
	329	320	1366:1000	10.6
230	330	257	1135	12.0
	327	321	1135:1000	16.7
	329	255	1215	16.2
	335	328	1215:1000	11.0
	330	260	1300	15.6
	334	327	1306:1000	15.1
250	320	240	1210	13.4
	332	324	1201:1000	8.7
	327	245	1243	11.8
	331	325	1243:1000	5.8
	320	240	1290	14.8
	329	324	1290:1000	6.5

* t_g = casting temperature, t_a = annealing temperature.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Arnold, *140*, (I): 107; 94. (2) Arnold and Knowles, *140*, (II): 76; 11. (3) Arnold and Read, *140*, (I): 169; 10. (4) Baker, *46*, **34**: 498; 05. (5) Baker, *140*, (II): 312; 03. (6) Campbell, *140*, (II): 359; 03. (7) Coe, *140*, (I): 361; 13. (8) Coe, *140*, (II): 105; 10. (9) Frilley, *74*, **8**: 457; 11.

(10) Guillet, *34*, **137**: 480; 03. (11) Guillet, *140*, (II): 1; 06. (12) Guillet, *74*, **1**: 46; 04. (13) Hadfield, *140*, (I): 147; 05. (14) Hadfield, *140*, (II): 41; 88. (15) Hadfield, *140*, (II): 222; 89. (16) Hadfield, *153*, **93**: 77; 87. (17) Hadfield, *153*, **93**: 1; 88. (18) Hadfield, *80*, **23**: 148; 94. (19) Hanemann and Schulz, *77*, **34**: 399, 450; 14.

(20) Hatfield, *140*, (II): 157; 06. (21) Hengstenberg, *77*, **44**: 914; 24. (22) Lang, *192*, **8**: 15; 11. (23) Leuenberger, *77*, **37**: 513, 601; 17. (24) Leuenberger, *77*, **41**: 285; 21. (25) Paglianti, *192*, **9**: 217; 12. (26) Portevin, *417*, (I): 230; 09. (27) Potter, *80*, **50**: 437; 14. (28) von Schwarz, *139*, **11**: 80; 13. (29) Stateler, *93*, **81**: 61; 13.

(30) Strauss, *212*, **4**: 665; 23. (31) Turner, *4*, **51**: 122; 87. (32) Turner, *133*, **1888**: 69. (33) Turner, *4*, **47**: 577, 902; 85. (34) Wahlberg, *140*, (I): 243; 01. (35) Wahlberg, *77*, **21**: 460; 01. (36) Wüst and Kettenbach, *139*, **11**: 65; 13. (37) Wüst and Meissner, *139*, **11**: 97; 13. (38) Yensen, *119*, **34**: 2455; 15.

STEELS CONTAINING Al, As, B, Ce, Sb, Ta, OR Zr

W. ROSENHAIN AND EDITH OWER

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TABLE 1.—TENSILE PROPERTIES AND HARDNESS OF AL-STEELS

1000 × % composition						Trt, v. p. 392	BHN	UTS	EL	El*	RA	Lit.
Al	C	Mn	Si	P	S							
C, < 0.10%												
507	85	Tr.	Tr.	29	13	F	81	37.1	26.7	35	68.0	(4)
						Q†	143	46.2	29.1	22	64.1	
7180	83	57	117	20	15	F	159	46.1	40.9	2	0	(4)
						Q†	192	45.3	45.3	0	0	
C, 0.10–0.15%												
1083	113	Tr.	70	16	14	F	105	40.8	33.6	30	65.2	(4)
						Q†	159	51.2	40.8	15	20.8	
						A‡	51	39.8	31.5	26	60.1	
3050	134	Tr.	105	16	13	F	131	41.4	27.4	23.5	32.9	(4)
						Q†	163	42.2	28.3	4	1.4	
C, 0.15–0.20%												
38o	15o	18o	18o	4o	10o	F		47.2	36.2	37.9	58.2	(7)
						A‡		40.9	31.5	40.4	60.7	
66o	18o	14o	16o	3o	9o	F		45.7	32.3	33.4	49.9	(7)
						A‡		42.5	28.3	33.0	52.1	
72o	17o	18o	10o			F		44.1	34.6	40.0	60.7	(7)
						A‡		39.4	28.3	47.1	64.9	
2045	168	Tr.	Tr.	8	22	F	118	44.5	27.9	28	66.7	(4)
						Q†	143	48.9	31.3	7.5	4.3	
5077	168	83	140	24	17	F	143	50.7	34.4	21	45.9	(4)
						Q†	192	47.3	33.5	2	0	
						A‡	131	44.3	33.5	2	0	
C, 0.20–0.25%												
15o	22o	7o	9o			F		45.7	33.0	36.7	62.9	(7)
						A‡		39.4	31.5	41.3	63.8	
61o	20o	11o	12o			F		44.1	33.9	38.4	54.5	(7)
						A‡		40.1	28.3	40.5	62.0	
160o	21o	18o	18o			F		48.8	31.5	32.7	52.1	(7)
						A‡		40.9	20.5	36.4	67.1	
220o	21o	18o	18o	3o	9o	F		48.8	33.0	22.8	27.8	(7)
						A‡		44.1	29.9	34.9	47.1	
224o	24o	32o	18o			F		51.2	33.9	20.7	24.6	(7)
						A‡		44.9	29.1	33.0	48.6	
560o	22o	22o	20o	3o	8o	F		59.8		3.7	4.0	(7)
						A‡		56.7	42.5	6.5	6.2	
C, 0.20–0 25% (castings)												
							Diam., mm					
45o	24o	54o	12o	23	25	GA	22.9	55.7	24.7	19.0	17.0	(11)
180o	20o	45o	20o	23	22	GA	16.3	54.3	26.8	13.0	17.0	(11)
275o	20o	50o	23o	22	20	GA	16.3	51.9	25.2	10.0	0.0	(11)
360o	23o	47o	20o	23	20	GA	14.7	51.3	26.8	2.5	0.0	(11)
460o	20o	50o	18o	22	20	GA	22.9	50.5	25.2	3.1	0.0	(11)
C, 0.25–0.30%												
116o	26o	11o	15o	4o	8o	F		51.9	36.2	32.1	51.5	(7)
						A‡		45.7	33.0	34.4	53.0	
23o	30o	40o	10o	27	22	GA	16.3	60.8	24.9	14.0	13.5	(11)
95o	28o	50o	15o	23	20	GA	16.3	55.1	25.2	13.0	15.0	(11)
270o	30o	125o	22o	25	23	GA	21.1	63.0	31.5	8.5	0.0	(11)
C, 0.30–0 75%												
							BHN					
45	736	100	140	15	8	F	228	83.3	45.7	5	17.3	(4)
1052	669	141	198	8	12	F	212	88.8	46.6	9	20.5	(4)
2890	691	152	186	6	18	F	228	73.8	43.6	4	4.5	(4)
						Q†	269	95.5	58.4	3	4.5	
700o	663	140	256	50	25	F	217	89.4	68.4	0	0	(4)
						Q†	255	102.5	75.8	0	0	
C, >0.75%												
1094	796	208	362	13	14	A‡	228	92.5	45.2			(4)
4650	815	122	221	24	24	F	277	88.8	46.7	11	15.4	(4)
1490o	860	398	232	32	18	F	277	101.9	66.2	3	42	(4)
						Q†	262	103.4	56.5	0	0	

* Test pieces (6) are 2 in. × 0.7979 in. diam.; dimensions of others not stated.
† 850° Q_w. ‡ A 900° /4 h.

TABLE 2.—COMPRESSION TESTS ON AL-STEELS (7)

Test pieces (as forged) subjected to compressive stress of 157.5 kg/mm².

100 × % composition						l_0*	d_0*	$-100\frac{\Delta l}{l_0}$	$100\frac{\Delta d}{d_0}$
Al	C	Mn	Si	P	S				
15	22	7	9			0.9970	0.7970	51.00	1.24
66	18	14	16	3	9	1.0025	0.7965	49.08	1.17
116	26	11	15	4	8	0.9985	0.7960	47.22	1.13
160	21	18	18			1.000	0.7972	48.10	1.14
224	24	32	18			1.0011	0.7969	45.40	1.11
560	22	22	20	3	8	0.9992	0.7966	36.57	1.04

* l_0 = original length, d_0 = original diameter.

TABLE 3.—SPECIFIC GRAVITY OF AL-STEELS

% composition*		d_4^{20}		Lit.
Al	C	Cast	Forged	
0.72	0.17		7.755	(7)
0.61	0.20		7.781	(7)
1.60	0.21		7.6237	(7)
2.24	0.24		7.554	(7)
5.6	0.22		6.6726	(7)
0.45	0.24	7.73	7.77	(11)
1.80	0.20	7.62	7.67	(11)
2.75	0.20	7.44	7.58	(11)
3.60	0.23	7.35	7.48	(11)
4.6	0.20	7.27	7.40	(11)
0.23	0.30	7.78	7.79	(11)
0.95	0.28	7.70	7.72	(11)
2.70	0.30	7.45		(11)

* For complete analyses, v. Table 1.

TABLE 4.—MECHANICAL PROPERTIES OF AS-STEELS

1000 × % composition							Trt,* v. p. 392	UTS	YP	El	RA	Lit.
As	C	Mn	Si	Cu	P	S						
C, <0.3 %												
123	77	436	58	168	17	54	A	35.7	26.1	27.2	55.3	(8)
							Q	41.2	27.4	27.9	52.2	
277	76	440	54	196	20	60	A	37.2	26.9	26.9	55.4	(8)
							Q	42.5	29.2	24.0	51.6	
405	78	431	57	182	17	57	A	38.5	27.1	26.5	55.8	(8)
							Q	43.8	31.7†	23.2	46.2	
549	77	448	52	192	18	52	A	39.5	27.3	25.9	55.1	(8)
							Q	44.4	31.9	23.0	45.4	
691	75	439	62	200	16	60	A	41.3	30.1	25.6	53.0	(8)
							Q	45.5	32.2	22.7	43.4	
880	76	435	54	207	20	55	A	42.0	31.6	25.6	52.4	(8)
							Q	48.0	34.9	21.7	39.2	
1172	81	433	49	198	23	55	A	44.0	33.8	25.3	51.2	(8)
							Q	48.3	35.8	22.8	42.8	
1425	80	429	49	192	26	51	A	46.0	34.3	20.8	42.3	(8)
							Q	47.9	34.8	21.6	33.3	
1570	40	10	30	‡	30	20	C_a	42.6	27.9†	28.5§	34.1	(1)
1621	83	434	46	188	26	55	A	48.8	36.1	20.2	34.1	(8)
							Q	48.8	34.7	18.6	27.5	
1943	79	434	47	184	21	56	A	47.5	36.7	8.9	15.5	(8)
							Q	50.4	35.2	11.9	9.8	
2240	83	429	52	187	24	55	A	42.5	36.6	5.15	9.1	(8)
							Q	49.4	34.3	10.0	2.8	
2534	86	446	55	192	19	52	A	41.0	36.9	4.55	1.1	(8)
							Q	49.8	38.6	9.10	1.7	
2841	84	440	55	189	21	50	A	36.5	35.5	1.88	0.0	(8)
							Q	44.1	39.2	4.14	1.1	
3130	85	446	53	193	17	57	A	35.7	35.7	0.0	0.0	(8)
							Q	44.4	44.0	1.97	0.0	
3284	85	442	59	186	17	51	A	35.1	35.1	0.0	0.0	(8)
							Q	39.5	38.8	1.10	0.0	
3515	68	352	46	152	13	40	A	35.8	38.8	0.0	0.0	(8)
							Q	38.8	38.8	0.0	0.0	

TABLE 4.—MECHANICAL PROPERTIES OF As-STEELS.—(*Continued*)

1000 × % composition						Trt,* v. p. 392	*UTS*	*YP*	*El*	*RA*	Lit.
As	C	Mn	Si	P	S						
C, 0.30–0.45 %											
93	360	114o	115	89	26	R..........	72.4	22.7	17	43	(10)
178	360	102o	123	55	40	R..........	57.5		20		(10)
185	355	100o	122	68	36	R..........	57.5		18.5		(10)
193	405	117o	147	74	26	R..........	78.7	28.5	13	28	(10)
197	365	120o	109	64	34	R..........	72.9	21.0	19	47	(10)
208	360	101o	125	55	40	R..........	58.3		19.5		(10)
266	400	111o	168	77	34	R..........	80.2	27.5	13	33	(10)
272	360	120o	103	88	36	R..........	72.4	21.5	17	41	(10)
274	395	112o	150	87	46	R..........	72.4	24.0	17	32	(10)
278	425	121o	153	83	36	R..........	77.3	28.5	22	29	(10)
293	355	94o	127	62	36	R..........	60.4		14		(10)
301	365	112o	94	94	40	R..........	72.4	26.5	16	43	(10)
328	365	100o	131	77	38	R..........	59.9		15.5		(10)
334	356	120o	109	97	36	R..........	74.5	22.0	16	36	(10)
340	400	116o	141	99	40	R..........	78.7	29.0	15	35	(10)
367	395	110o	141	97	34	R..........	80.0	32.0	15	27	(10)
618	355	100o	125	72	40	R..........	59.5		16		(10)
672		930	94	84	44	R..........	62.5		20		(10)

TABLE 4.—MECHANICAL PROPERTIES OF As-STEELS.—(*Continued*)

1000 × % composition						Trt,* v. p. 392	*UTS*	*YP*	*El*	*RA*	Lit.
As	C	Mn	Si	P	S						
C, > 0.45 %											
243	495	110o	177	63	50	R..........	89.3	32.0	12	25	(10)
278	490	111o	156	77	40	R..........	83.6	31.0	10	12	(10)
278	500	109o	156	63	46	R..........	84.4	30.0	12	20	(10)
296	500	108o	195	87	34	R..........	88.6	33.5	11	19	(10)
317	515	109o	141	91	40	R..........	87.2	35.0	11	16	(10)
329	505	117o	125	86	44	R..........	85.8	32.0	13	20	(10)

* A = A 880°/90 C_s (in absence of air); Q = 910°/40 Q_w; C_a = R (1 in. diam.), W > 1000°, C_a; R = from head of a rail.

† These values are for elastic limit.

‡ Contains 0.003 % Al. $d^{20}_{4} = 7.8690$.

§ Test pieces from rolled bars, 2 in. × 0.564 in. diam.

COMPRESSION TEST OF 0.04 % C-STEELS CONTAINING As (1)

100 × % composition							CS / Trt*	% compression				
As	C	Mn	Si	Al	P	S		31.5	63.0	94.5	126.0	157.5
157	4	1	3	3	3	2	N......... H.........	3.0 0.9	15.5 12.3	31.4 27.0	44.6 40.3	53.0 49.1

* N = normalised; H = W > 1000° Q_w (test pieces 28.7 mm × 14.32 mm diam.).

TABLE 5.—MECHANICAL PROPERTIES OF B- AND Ni-B-STEELS

Boron steels difficult to roll at ordinary rolling temperature (1100°C). Ingots for (2): specimens rolled at 960°, but some plates showed cracks.

% composition								Trt, v. p. 392	*UTS*	*YP*	*PL*	El_a*	*RA*	*BHN*	*ScH*	*IS*† kg/m	*IS'*‡ kg-m/cm²	Lit.
B	C	Ni	Al	Mn	Si	P	S											
B-Steels																		
0.215	0.180			0.076	0.232	0.023	0.012	N 850° Q_w	37.4 68.4		20.2 57.0	34.5 7.5	57.5 36.5			3.05 5.95		(5)
0.39	0.16		0.06	0.68	0.24	<0.015	<0.035	N 880° 880° Q_o Tp	49.1 67.5	32.5	 35.8	10.7 3.9	23.8 19.1	156 217	15 30		0.79	(2)
0.462	0.224			0.292	0.163	0.015	0.015	N 850° Q_w	39.6 147.5		20.2 99.9	27.0 6.5	55.0 30.6			3.05 5.95		(5)
0.57	0.21		0.02	0.80	1.50	<0.015	<0.035	N 880° 880° Q_o Tp	59.5 105.4	40.8 103.6	38.0 56.9	11.5 0.5	25.6 9.8	217 555	 43		1.03	(2)
0.844	0.207			0.600	0.792	0.013	0.014	N 850° Q_w	50.1 174.9		29.8 129.9	14.0 4.0	26.8 10.6			3.05 5.95		(5)
1.514	0.281			0.600	0.641	0.018	0.005	N 850° Q_w	51.7 126.0		31.5 120.0	5.5 1.0	4.5 0.0			1.94 3.05		(5)
0.06	0.45		0.03	0.69	0.33	<0.015	<0.035	N 820° 820° Q_o Tp§	70.6 60.0	59.6		17.0 0.1	41.7 0.7	187 387	23 52		0.77	(2)
0.155	0.475			0.370	0.283	0.020	0.020	N	50.9		34.5	17.0	27.0			1.94		(5)
0.406	0.595			0.295	0.292	0.023	0.016	N	54.0		39.0	18.0	22.8			3.05		(5)
Ni-B-Steels																		
0.09	0.16	3.00	0.02	0.84	1.20	<0.015	<0.035	N 850° 850° Q_o Tp§	77.5 120.0		28.1 80.1	10.5 0.8	10.6 2.7	220 387	22 38		3.45	(2)
0.30	0.18	3.00	0.02	0.77	1.30	<0.015	<0.035	N 880° 880° Q_o Tp§	46.2 146.4		33.7 78.7	14.0 3.2	5.4 2.0	196 380	21		1.03	(2)
0.50	0.19	3.05	Tr.	0.67	0.41	<0.015	<0.035	N 820° 820° Q_o Tp§	63.7 150.7	45.7 119.3	38.7 79.4	10.8 4.3	20.8 5.9	175 387	 52		0.99	(2)
0.10	0.26	3.55		0.58	0.36	<0.015	<0.035	N 800° 800° Q_o Tp§	113.0 159.3	 144.2	37.3 94.9	12.0 2.3	46.8 7.9	205 470	24 60		2.34	(2)
0.10	0.47	2.80	0.02	0.67	1.25	<0.015	<0.035	N 760° 760° Q_o Tp§	84.8 180.0	 172.0	49.2 70.3	17.0 3.0	31.1 7.9	262 425	35 55		0.75	(2)
0.08	0.69	2.90	0.01	0.50	0.36	<0.015	<0.035	N 840° 840° Q_o Tp§	98.3 227.1	93.4	40.1 119.5	11.0 3.0	22.6 3.5	285 600	34 68		0.88	(2)

* In (2) specimens are 2 in. × 0.3 in. diam. *PL* by Berry strain gage.

† Machine and type of specimens not stated.

‡ Tests made on Izod machine. Specimens: 0.35–0.45 in. diam., 45° V notch, 0.13 in. deep, bottom radius = 0.01 in.

§ Tp = Tp_0 175°/3 h, C_a.

TABLE 7.—MECHANICAL PROPERTIES OF CE- AND NI-CE-STEELS (2)

% composition*					Trt, *v*. p. 392	*UTS*	*YP*	*PL*	*El*‡	*RA*	*BHN*	*ScH*	*IS'*§ kg-m/cm²
Ce†	C	Ni	Mn	Si									
Ce-Steels													
0.20	0.39		0.68	0.75	N 840°	65.8	39.8	26.0	6.3	54	163	17	
					840° Q_o Tp‖	90.1		59.7		0.7	418	32	1.54
0.35	0.40		0.69	0.27	N 820°	59.5	50.0	19.0	8.5	31.1	185	25	
					820° Q_o Tp‖	132.7		84.3		10.0	248	128	2.75
Ni-Ce-Steels													
0.01	0.45	2.95	0.71	1.30	N 820°	101.1	94.4		15.6	40.8	269	24	
					820° Q_o Tp‖	218.8	145.1		8.5	37.2	555	52	1.54
0.06	0.41	2.80	0.73	1.70	N 840°	100.8		42.2	7.5	37.6	285	39	
					840° Q_o Tp‖	209.3	172.0	123.0	7.5	7.2	555	58	3.73
0.10	0.46	2.90	0.98	1.55	N 840°	123.9	72.6	38.0	9.5	5.4	321	41	
					840° Q_o Tp‖	219.5	165.2	129.3	4.6	7.3		66	1.54
0.31_T	0.42	2.95	1.15	0.80	N 780°	89.4	56.2	37.2	21.0	17.8	217	37	
0.19_B					780° Q_o Tp‖	142.3	104.7	45.7	8.6	10.4	222	57	2.08
0.55_T	0.44	3.00	0.91	1.30	N 800°	111.5	100.3		5.5	17.3	302	36	
0.35_B					800° Q_o Tp‖	228.2	203.0	58.3	5.5	11.0	600	51	5.41
1.35_T	0.39	2.65	0.90	0.25	N 780°	76.7	52.0	35.2	7.6	16.0	187	34	
0.66_B					780° Q_o Tp‖	124.8	108.6	64.0	2.5	2.1			1.46
0.03	0.51	2.90	1.04	1.35	N 780°	108.4		49.2	1.0		396	40	
	(+Cu 0.62)				780° Q_o Tp‖	176.8		98.4	1.0	14.1	530	52	1.01
0.22_T	0.74	2.25	0.82	1.25	N 805°	120.2	81.0	70.3	10.5	36.1	359	48	
0.07_B					805° Q_o Tp‖	(Broke in shoulder)							1.01

* These steels contain <0.015 % P, <0.035 % S.

† Where two values are given for % Ce, subscripts T and B refer to samples taken from top and bottom of ingot respectively (in amounts over 0.30 %, Ce segregates very badly).

‡ Tensile specimens 2 in. × 0.30 in. diam.

§ Izod machine used. Specimens 0.30 in. to 0.45 in. diam., 45° V notch, 0.13 in. deep, bottom radius = 0.01 in.

‖ Tp = Tp_o 175°/3 h C_a.

TABLE 6.—HARDNESS OF B-STEELS* (3)

% B	% Ni	*BHN*†	% B	% Ni	*BHN*†	% B	% Ni	*BHN*†
0.4		108.5	0.78	4.75	242.5	2.1	10.7	435
0.73		175	0.85	4.72	242.5	2.51	10.0	454
1.21		227	1.32	4.80	341.5	3.38	10.4	571.5
1.93		242.5	2.18	5.0	521.5	4.24	10.0	712
2.41		214	2.52	4.7	356	0.69	20.0	385.5
3.26		318	3.15	4.93	521.5	2.17	19.81	400.0
4.32		560	4.41	4.81	521.5	1.04	22.0	208?
2.3	1.3	227	2.39	7.0	418	1.42	25.0	400
4.27	1	571.5	0.71	10.2	355	3.9	25	296
2.76	2.1	250	0.84	10.2	370			
4.32	2	712	1.31	10.25	419			

* Prepared from Swedish iron containing: C, 0.1; Mn, 0.14; Si, 0.014; P, 0.08; S, 0.012; ferroboron containing B, 19.56; C, 0.17; and pure Ni.

† 10 mm, 3000 kg.

TABLE 9.—SPECIFIC GRAVITY OF FE-SB-ALLOYS (9)

% Sb..	18.80	38.80	44.98	56.88	60.80	64.58	74.31	81.52
d_4^0....	7.800	8.120	8.159	8.298	8.071	8.300	7.912	7.211

TABLE 8.—PROPERTIES OF SB-STEELS (12)

100 × % composition							*UTS*	*YP*	*El*†	*RA*	d_4^{20}
Sb	C	Cu	Mn	Si	P	S					
2	10	6	37	4	Tr.	7	35.4	20.0	33.5	75.0	
5	11	16	56	4	Tr.	5	34.4	20.5	30.1	75.0	8.2

† Test pieces 56 mm × 5.65 mm.

TABLE 10.—MECHANICAL PROPERTIES OF TA-STEELS (6)

% composition*				Trt, *v*. p. 392	*UTS*	*EL*	*El*†	*RA*	*BHN*
Ta	C	Mn	Si						
0.09	0.12	0.19	0.12	N	41.5	29.8	33	67.4	107
				875° Q_w 20°	65.0	46.9	14.5	71	159
0.15	0.17	0.15	0.19	N	42.6	30.4	31	68.8	107
				875° Q_w 20°	62.1	45.7	15	73	153
0.60	0.18	0.22	0.24	N	45.3	31.1	28	67.4	112
				875° Q_w 20°	65.8	46.6	13	74.9	155
1.05	0.16	0.23	0.16	N	47.8	31.5	28	62.3	116
				875° Q_w 20°	70.0	49.1	10	55.8	169

* All contain traces of P and S.

† Dimensions of test pieces not stated.

TABLE 11.—PROPERTIES OF ZR- AND NI-ZR-STEELS ([2])

% composition*							Trt, *v.* p. 392	*UTS*	*YP*	*PL*	El_a†	*RA*	*BHN*	*ScH*	*IS'*‡ kg-m/cm²
Zr	C	Ni	Mn	Si	Al	Ti									
Zr-Steels															
0.25	0.23		0.61	1.30	Tr.	0.05	N 900°	55.7	31.6	19.7	28.5	60.8	179	24	
							900° Q_o Tp§	69.7	43.8	16.2	23.5	55.0	187	22	5.08
0.20	0.37		0.50	0.73	0.02	0.03	N 860°	66.8	35.5	21.1	10.0	22.8	179	27	
							860° Q_o Tp§	69.9		16.9	9.5	21.3	196	25	
0.22	0.36		0.77	1.70	Tr.	0.06	N 860°	75.0		30.2	24.5	53.0	206	17	
							860° Q_o Tp§	135.4		63.2	5.0	19.8	286	35	1.76
0.50	0.33		0.63	1.5	Tr.	0.10	N 860°	65.0	33.7	22.5	22.5	51.5	189	27	
							860° Q_o Tp§	95.3		24.6	9.0	30.1	228	27	2.49
0.60	0.34		0.69	1.70	Tr.	0.07	N 860°	70.8	43.6		24.5	53.7	207	30	
							860° Q_o Tp§	98.6	64.6		12.5	26.8	187	31	2.66
0.03	0.45		0.67	0.50	0.02	0.02	N 825°	69.6		29.5	19.5	39.8	185	27	
							825° Q_o Tp§	115.6		38.0	5.0	8.5	241	27	
0.03	0.42		0.76	1.55	Tr.	0.03	N 860°	81.1	53.8	33.0	19.0	52.3	212	29	
							860° Q_o Tp§	104.5	90.2	52.7	1.5	32.0	269	31	2.70
0.11	0.47		0.78	0.85	0.15	0.02	N 800°	77.8		21.8	16.0	22.7	207	31	
							800° Q_o Tp§	103.6		35.1	0.5	2.2	292	28	
0.15	0.42		0.55	0.44	0.13	0.01	N 860°	71.0	37.4	27.4	8.0	20.3	186	25	
							860° Q_o Tp§	165.9	144.8	88.6	1.5	4.5	509	54	
0.09	0.56		0.75	0.54	0.07	0.02	N 810°	70.8	39.3	35.1	11.0	18.7	197	27	
							810° Q_o Tp§	142.5			0.25	0.0	454	43	
0.10	0.51		0.80	1.15	0.09	0.04	N 840°	81.0		37.2	16.0	38.6	228	29	
							840° Q_o Tp§	184.1		56.2	1.5	2.0	520	44	
Ni-Zr-Steels															
0.12	0.39	3.15	0.90	1.05	0.01	0.02	N 830°	182.0		37.9	4.0	5.2	375	32	
							830° Q_o Tp§	188.0		95.6	1.0	4.5	512	39	
0.13	0.43	2.00	0.87	1.10	0.17	0.11	N 820°	98.2	61.1	42.9	19.5	44.9	255	31	
							820° Q_o Tp§	206.3		116.6	7.0	24.1	477	37	2.32
0.25	0.51	3.00	0.72	1.20	0.04	0.01	N 780°	137.1		42.2	4.0	11.6	255	20	
							780° Q_o Tp§	204.7		81.9	3.0	4.0	440	36	

* All steels contain < 0.015 % P and < 0.035 % S.
† Tensile specimens, 2 in. × 0.3 in. diam.
‡ Izod machine specimens 0.30–0.45 in. diam., 45° V notch, depth = 0.13 in., radius of bottom = 0.01 in.
§ Tp = Tp 175°/3 h C_a.

LITERATURE

(For a key to the periodicals see end of volume)

([1]) Arnold, *140*, **45**: 107; 94. ([2]) Burgess and Woodward, *32*, No. **207**; 22. ([3]) Chiyevskii and Mikhailovskii, *74*, **14**: 16; 17. *431*, **1**: 547; 15. ([4]) Guillet, *74*, **2**: 312; 05. ([5]) Guillet, *34*, **144**: 1049; 07. ([6]) Guillet *34*, **145**: 327; 07. ([7]) Hadfield, *140*, **37**: 161; 90. ([8]) Liedgens, *77*, **32**: 2109; 12. ([9]) Maey, *7*, **38**: 292; 01. ([10]) Mitinsky, *431*, **1**: 650; 13. *10*, **4**: 1324. ([11]) Riley, *140*, **36**: 161; 90. ([12]) Schleicher, *77*, **42**: 781; 22.

PROPERTIES OF ALUMINIUM AND ITS ALLOYS WITH CU, MG, MN, NI, SI, SN, AND ZN CONTAINING MORE THAN 50% Al (*v. also* p. 542)

S. L. ARCHBUTT

The following properties of pure Al are given elsewhere: specific gravity, p. 456; compressibility, vol. III; viscosity, vol. III; surface tension, vol. III.

TABLE 1.—TENSILE PROPERTIES

Al

% composition*	Treatment	*UTS*	*YP*	*PL*	*El*	*RA*	Lit.
Al, 99.97	Wk, A	5.96			60_a	95	([10])
Al, 99.6; Fe, 0.14; Si, 0.19	R, 1/8 in. thick†	4.41–6.43			$34–86_b$		([8])
	R, rod‡	4.7–6.3			$55–87_b$		
Al, 99.54; Fe, 0.14; Si, 0.25; Na, 0.07	G_s, 0.56 in.§	7.72	3.9		24_a	39.4	([7])
	G_s, 450° C_s	7.21	3.0		19.0_a	27.4	
	G_s, 450° Q_w	7.95	3.8		22.0_a	33.8	
	G_m, 1 in.	8.23	3.6		37.0_a	60.7	
	R_h, 3/4 in.§	10.24	6.9		35.5_a	79.4	
	R_h, 13/16 in.§	11.34	10.2		30.5_a	81.2	
	DA, 13/16 in.§	11.69	11.0		23.0_a	82.1	
	D_c, 13/16 in.§	13.70	13.4		19.5_a	73.3	
R_c sheet	1/4 in. thick	13.16	12.4		10.6_b		
	Same, A 500°	9.31	4.25		41.0_b		
	1/10 in. thick	14.45	13.5		6.3_b		
	Same, A 500°	9.29	4.7		31.0_b		
	1/20 in. thick	14.71	13.2		3.7_b		
	Same, A 500°	9.18	4.0		36.3_b		
Al, 99.30	R_d sheet	15.5–24.6			$1–7_a$	20–30	([6])
	R_d bars	19.7–24.6				30–40	
	D_d wire	17.6–38.7				40–50	
Al, 99.24; Fe, 0.49; Si, 0.15‖	R, 3/4 in. diam.	15.90		7.92	16_a	65.4	([22])
Al, 99.20	G_s, 1/2 in.	9.5	2.8¶	0.7	24**		([11])
	Wk_d, 75 %	15.8	12.7	7.0	13		
	Same, A	9.5	3.2	1.4	40		
Al, 99.07–98.46; Fe, 0.70–0.98; Si, 0.23–0.56	Strip, A††	9.0–10.1		4.6–3.9	$40–38_l$		([14])
	R_c, 50 %	14.2		11.5–12.0	$9–11_l$		
	R_c, 200–300 %	15.0–18.1		14.2–17.6	$2–1.5_l$		
	Same, A 400°‡‡	10.99		5.0	40_l		

* Al content by difference.
† Single crystal, test piece 1 × 1/8 in. cross-section.
‡ Single crystal, test piece 0.564 in. diam.
§ Dimensions are for diam. after indicated mechanical treatment, test piece, 0.564 in. diam.
‖ Contains 0.12 % Cu.
¶ Stress at Δl = 1/2 % l_0.
** Gage length = 4 × diam.
†† 0.5–10 mm thick from 40 mm slabs.
‡‡ Optimum conditions for completely annealed product (Grard).

Al-Cu* ([7])

Treatment	*UTS*	*YP*	El_a†	*RA*	*UTS*	*YP*	El_a†	*RA*
	Cu, 0.86%				Cu, 1.90%			
G_s, to shape	8.06	4.1	12.5	12.1	7.20	5.2	5.5	18.4
Same 450 C_s	8.24	3.9	10.5	11.8	7.32	5.2	6.0	22.7
Same 450° Q_w	8.95	4.4	13.0	21.5	7.89	5.7	7.0	9.1
G_m, 1 in. diam	9.64	4.9	15.5	33.3	12.88	6.1	17.0	26.4
R_h 3/4 in. diam	14.72	8.7	30.0	72.9	17.16	10.1	27.5	61.7
R_h 7/8 in. diam	16.49	12.0	28.5	73.3	22.66	20.2	19.0	58.2
DA, 13/16 in	16.90	16.1	19.0	71.7	21.72	20.3	16.5	59.4
D_c, 13/16 in	20.27	19.2	14.5	63.3	23.62	22.1	13.0	46.5
	Cu, 0.93% (sheet)				Cu, 1.57% (sheet)			
R_c, 1/4 in. thick	18.8	17.3	7.0		21.72	20.5	5.3	
Same, A 500°	12.9	5.8	28.7		15.78	7.1	24.7	
R_c, 1/10 in. thick	20.4	18.1	4.7		25.5	20.0	5.3	
Same, A 500°	12.7	6.0	31.7		16.42	7.2	25.3	
R_c, 1/20 in. thick	19.2	18.4	3.3		23.89	21.7	3.3	
Same, A 500°	13.4	5.4	29.2		16.70	6.5	25.7	

Al-Cu* ([7]).—(*Continued*)

Treatment	*UTS*	*YP*	El_a†	*RA*	*UTS*	*YP*	El_a†	*RA*
	Cu, 2.77%				Cu, 3.76%			
G_s, to shape	8.22	5.8	4.5	11.0	11.80	7.7	5.0	7.3
Same 450° C_s	8.76	6.8	5.0	7.3	11.84	7.7	4.0	12.0
Same 450° Q_w	8.41	7.2	5.0	8.0	11.10	9.0	4.0	12.2
G_m, 1 in. diam	13.54	7.7	10.5	24.6	15.12	8.5	10.5	21.5
R_h 3/4 in. diam	21.87	10.6	26.5	52.2	26.5	14.2	20.0	38.2
R_h 7/8 in. diam	26.1	19.7	16.0	44.6	26.8	18.3	21.0	49.8
DA, 13/16 in	Drew hollow‡				26.6	24.4	8.0	21.8
D_c, 13/16 in.§	28.0	25.8	9.5	27.6	31.5	29.1	7.5	20.8
	Cu, 2.36% (sheet)				Cu, 3.74% (sheet)			
R_c, 1/4 in. thick	22.24	21.1	4.3		24.58	23.5	4.0	
Same, A 500°	15.25	7.9	28.6		16.95	6.8	24.0	
R_c, 1/10 in. thick	23.37	18.3	5.3		27.7	26.5	4.0	
Same, A 500°	18.26	7.6	25.3		17.32	8.0	21.0	
R_c, 1/20 in. thick	26.54	24.1	4.0		29.25	25.0	4.0	
Same, A 500°	18.53	7.1	24.7		18.36	7.7	24.7	
	Cu, 4.97%				Cu, 6.15%			
G_s, to shape	10.60	8.2	4.0	5.0	12.16	9.6	‖	3.5
Same 450° C_s	12.36	8.7	4.0	1.2	11.46	10.2	3.0	5.0
Same 450° Q_w	11.51	9.8	4.0	1.1	12.76	11.0	3.5	1.5
G_m, 1 in. diam	15.15	9.3	6.0	9.7	15.62	8.3	5.0	10.6
R_h 3/4 in. diam	23.10	14.0	19.5	36.9	25.78	14.3	18.0	33.8
R_h 7/8 in. diam	23.86	16.4	19.5	36.4	27.20	20.6	15.5	33.6
D_c, 13/16 in	27.9	25.0	6.0	20.8				
	Cu, 4.74% (sheet)				Cu, 5.34% (sheet)			
R_c, 1/4 in. thick	25.22	23.3	2.0		21.36	19.7	‖	
R_c, 1/10 in. thick	23.89	22.5	4.7		20.90	19.4	‖	
Same, A 500° (?)	24.91	21.7	4.6		21.22	19.5	2.0	
R_c, 1/20 in. thick¶	26.40	23.2	4.0		26.02	22.5	‖	
Same, A 500°	18.79	7.6	18.7		19.16	8.8	21.7	
	Cu, 6.91%				Cu, 8.08%			
G_s, to shape	9.67	8.2	2.0	1.6	11.65	10.2	‖	2.0
Same 450° C_s	9.18	9.1	‖	1.2	11.15	9.3	‖	1.6
Same 450° Q_w	12.14	9.6	3.0	1.6	12.65	12.0	3.0	1.7
G_m, 1 in. diam	14.84	9.6	4.0	4.6	16.76	11.3	‖	1.6
R_h, 3/4 in. diam	24.21	14.2	13.5	11.5	23.08	13.2	17.5	23.3
R_h, 7/8 in. diam	25.28	19.2	14.5	27.6	24.11	17.3	17.5	27.6
D_c, 5/8 in. diam					25.9	24.3	5.5	15.0

Treatment \ % Cu**		10.7	16.0	19.9	29.0	31.7
G_s, to shape	*UTS*	10.51	11.52	10.61	9.92	9.45
G_m, 1 in. diam	*UTS*	13.68	9.86	11.64	14.86	14.26

* Prepared from notch bar Al of analysis: Al (by diff.), 99.54; Si, 0.25; Fe, 0.14; Na, 0.07.
† Test pieces, 2 in. × 0.564 in. diam. for rounds and 3 in. × 1 in. wide for sheet.
‡ Also true for alloys containing >3.76 % Cu.
§ For 3.76 % Cu, D_c to 23/32 in. diam.
‖ Broke outside gage marks.
¶ Extra annealing at 0.07 in. thickness.
** El_a = 0.0 for all.

Effect of Heat Treatment and Aging on Al-Cu (16)

% Cu*	Treatment		UTS	El_a
3.95	G_m, 1 in. diam		16.8	12
	W 500°/24 h Q	V20° 6 d	24.9	13
		V100° 1 h	25.0	18
4.04	Strip† W 500°	C_f	19.4	30
		Q V 5 d	30.4	22
4.38	G_m, 1 in. diam.		18.4	14.5
	W 500°/24 h Q	V20° 6 d	26.4	17
		V100° 1 h	27.2	25
4.53	Strip† W 500°	C_f	18.9	23
		Q V 5 d	32.6	21
4.91	G_m, 1 in. diam		18.6	9
	W 500°/24 h Q	V20° 6 d	23.4	7‡
		V100° 1 h	22.5	9
4.98	Strip W 500°	C_f	19.4	28
		Q V 5 d	35.8	25

* Alloys prepared from notch bar Al of analysis: Al (by diff.), 99.62; Si, 0.19; Fe, 0.19.
† 0.10 in. thick from 1 in. diam. cast bars.
‡ On 1 inch.

Commercial Al-Cu

% Cu	Name	Treatment	UTS	YP	PL	El_a	Lit.
4.0	Cu, 4 %	G_s (0.5 in. diam.) Trt	23	$12._7$*	7.0	7.0	(11)
4.5† nom.	Cu, 4.5 %	G_m, 1 in. diam.	17.3			14.0	(16)
		Same, Trt, V	26.8			25.0	
4.98†		R W 500°/1 h Q V	35.8 (strip 0.1 in. th.)			25	(16)
5.7†	Cu, 6 %	G_s 1 in. diam.	11.5			3	(1)
		G_m 1 in. diam.	13.7			5	
7.75†	L 11 (Gr. Brit.) or No. 12 (U. S. A.)	G_s 1 in. diam.	10.7	3.9		3	(1)
		G_m 1 in. diam.	13.8_5	6.1		2	
8.00		G_s, 0.5 in. diam.	13.4	7.1*	4.25	1.0	(11)
8.08†		G_s, 0.6 in. diam.	11.6_5	10.2		‡	(7)
		G_m, 1 in. diam.	16.8_5	11.3		‡	
12† nom.	L 8	G_s 1 in. diam.	12.6	7.9		1	(23)
		G_m 1 in. diam.	13.4–15.3			1–1.5	
11–13§	L 8	G_s, 1 in. diam.	13.5 mean			1	(1)
			11.6–14.3		2.2–3.5	1	
		G_m, 1 in. diam.	19.1 mean			1	
			17.5–20.8		2.5–4.4	1–2.5	
12.48†	L 8	G_s 1 in. diam. (max. IS)	12.4			1	(1)
		G_m 1 in. diam. (max. IS)	13.4			1.5	

* Proof stress, max. $\Delta l = \frac{1}{2}\%\ l_0$.
† Nominal Fe and Si content each 0.20 %.
‡ Broke outside gage marks.
§ Fe and Si content each ≯1 %.

Al-Cu-Mg-Si and Al-Cu-Fe-Mg

Treatment		UTS	YP	PL	El_a	RA	Lit.
Al; Cu, 3.25; Mg, 0.70; Mn, Tr.; Fe, 0.28; Si, 0.28							
R ½ in. and 1 in. diam.	495° Q	35.9		15.9	16	50	(21)
	495° Q 100°/2 h	35.3		13.1	29	48	
	370°/20 C_f	17.8		4.7	25	61	
Al; Cu, 4.0; Fe, 2.0; Mg, 0.50							
G_s	1 in. diam. bar	17.2	14.6		2.0		(1)
G_m	1 in. diam. bar	21.7	16.1		5.2		

Al-Cu-Mn (27)

Trt*	% composition	UTS	YP	El_a
G_s	Cu, 1.27; Mn, 2.06	10.7_6	8.9	4.7
G_m		9.7_3	9.7	6
G_s	Cu, 2.15; Mn, 0.88	9.7_0	7.4	5
G_m		13.4_4	8.7	6
G_s	Cu, 2.02; Mn, 1.90	10.0_5	9.3	3
G_m		15.3_7	9.8	7

Al-Cu-Mn (27).—(*Continued*)

Trt*	% composition	UTS	YP	El_a
G_s	Cu, 2.15; Mn, 1.91	12.7_5	10.5	5
G_m		15.7_5	12.3	5
G_s	Cu, 2.06; Mn, 1.94	13.3_5	9.1	4.0
G_m		14.2_6	10.1	5.0
G_s	Cu, 3.11; Mn, 0.57	10.8_5	7.9	4
G_m		13.0_0	7.9	5.5
G_s	Cu, 2.89; Mn, 0.94	11.7_8	9.5	5.0
G_m		18.9_7	11.4	$13._5$
G_s	Cu, 3.28; Mn, 0.98	9.8_6	8.0	4
G_m		13.2	9.9_5	5
G_s	Cu, 2.89; Mn, 1.76	12.0_3	10.1	$3._5$
G_m		10.7_1	9.6	5
G_s	Cu, 4.13; Mn, 1.92	2.2_7	2.2_7	$2._5$
G_m		13.0_4	10.0_4	$3._5$

* G_s = Cast to shape. G_m = 1 in. diam. Test piece diam. = 0.564 in.

% Cu	% Mn	Treatment	UTS	YP	PL	El_a	RA	Lit.
2.06	1.94	R_h, 1¼ in. diam.	25.9	15.9		18.5	39.5	(27)
		R_h, ¹¹⁄₁₆ in. diam.	26.8	19.1	11.3	16.0	37.6	
		DA, ¹¹⁄₁₆ in. diam.	28.9	17.8		6.0	11.2	
2.89	0.94	R_h, 1¼ in. diam.	24.8	13.9		20.0	32.8	(27)
		R_h, ¹¹⁄₁₆ in. diam.	26.0	20.2	11.3	15.0	38.0	
		DA, ¹¹⁄₁₆ in. diam.	Drew hollow					
4.5	0.70	Wk, A	$18._2$	5	3	24.0*		(11)
Also 0.80 % Si		Wk, Trt	$41._1$	23	14	22.0*		
14.13	0.90†	G_s 1 in. diam.	12.1	7.9		1.0		(1)
		G_m 1 in. diam.	15.6	8.3_5		1.0		
14.0‡	1.0‡	G_m, 1 in. diam.	14.6_5		6.3			(1)

* Gage length = 4 × diam.
† Contains Si, 0.20; Fe, 0.20 (nominal).
‡ Nominal content, max. allowable Fe and Si, each 1 %.

Al-Cu-Mn-Mg-Si; Duralumin

Treatment	UTS	YP	PS*	El	RA	Lit.
Al; Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5						
Sheet, 7 mm thick, Alloy H	36.0	19.1		25_a		(9)
Sheet, 7 mm thick, Alloy 681 D	45.9	26.0		17.5_a		
Other alloys give intermediate values						
Sheet, R_c, 7–2 mm (681 D)	62.0	54.0		3.0_a		(9)
Al; Cu, 3.5–4; Mn, 0.5–1; Mg, 0.5						
Sheet, 10 mm thick	40.0	20.0		20_d		(14)
Same, A 350°	20.0	6.9		14_d		
Same, 375° Q_2	40.0	23.0		22_d		
Rod, 5.1–12.7 mm diam	43–46	27–31		$14–24_l$		(13)
Al; Cu, 3.5–4.5; Mn, 0.4–0.7; Mg, 0.4–0.7; Fe, 0.75; Si, 0.60						
Rod < 2¼ in. diam	39.4		23.6	15_a	20	(4)†
Rod > 2¼ in. diam	26.8		21.3	15_a	18	
Sheet < 0.02 in. thick	39.4		23.6	8_a		
Sheet 0.02–0.048 in. thick	39.4		23.6	12_a		
Sheet > 0.048 in. thick	39.4		23.6	15_a		
Forged connecting rods‡	40.8		33.4	16_a		(23)
	46.0		30.2	14_a		
R (rod) C(−80°/10 m) J	41.1	21.5		26.5_a		(26)

* Stress at $\Delta l = \frac{1}{2}\%\ l_0$.
† British Standard Specifications, minimum values.
‡ Test pieces from web.

Al-Cu-Ni-Mg-Si

Treatment		UTS	YP	PL	El_a	RA	Lit.
Al, 92; Cu, 4.0; Ni, 2.0; Mg, 1.5; Fe, 0.20*; Si, 0.20* "Y" alloy							
G_s, 1 in. diam. bars		16.5			0.5		(23)
G_s, W 500–520° (6 h)	Q_b V 10 da	25.2			0.5		
	C_a V 10 da	22.8	21.3		1.0		
G_m, 1 in. diam. bars		22.8	17.3		2.5		
G_m, W 500–520° (6 h)	Q_b V 10 da	31.5	25.2	11.0	5.0		
	C_a V 10 da	29.9	23.6		2.0		

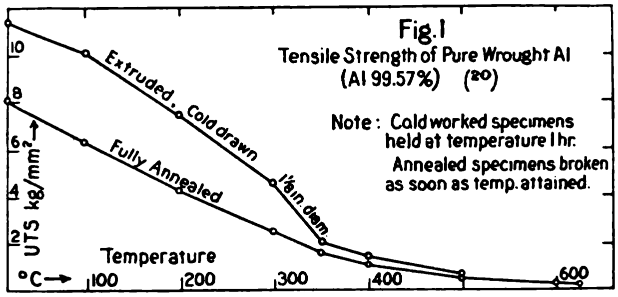
Fig.1
Tensile Strength of Pure Wrought Al
(Al 99.57%) (20)
Note: Cold worked specimens held at temperature 1 hr.
Annealed specimens broken as soon as temp. attained.
Extruded, Cold drawn
1⅛ in. diam.
Fully Annealed
UTS kg/mm² →
Temperature
°C →
10
8
6
4
2
100
200
300
400
600

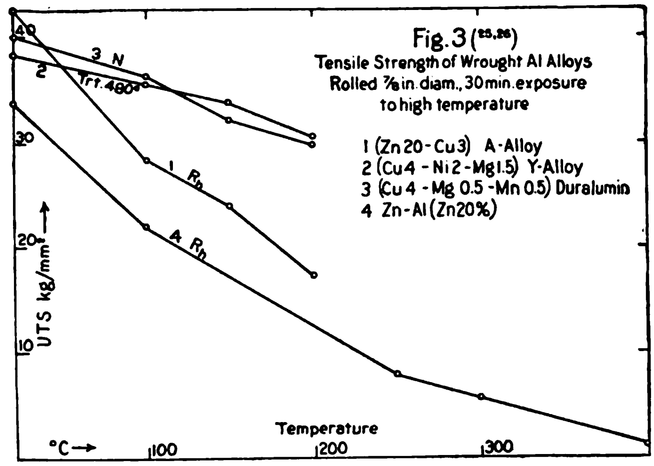
Fig.3 (25,26)
Tensile Strength of Wrought Al Alloys
Rolled ⅞ in. diam., 30 min. exposure to high temperature
1 (Zn 20 - Cu 3) A-Alloy
2 (Cu 4 - Ni 2 - Mg 1.5) Y-Alloy
3 (Cu 4 - Mg 0.5 - Mn 0.5) Duralumin
4 Zn-Al (Zn 20%)
3 N
2 Trt. 480°
1 Rh
4 Rh
UTS kg/mm² →
Temperature
°C →
40
30
20
10
100
200
300

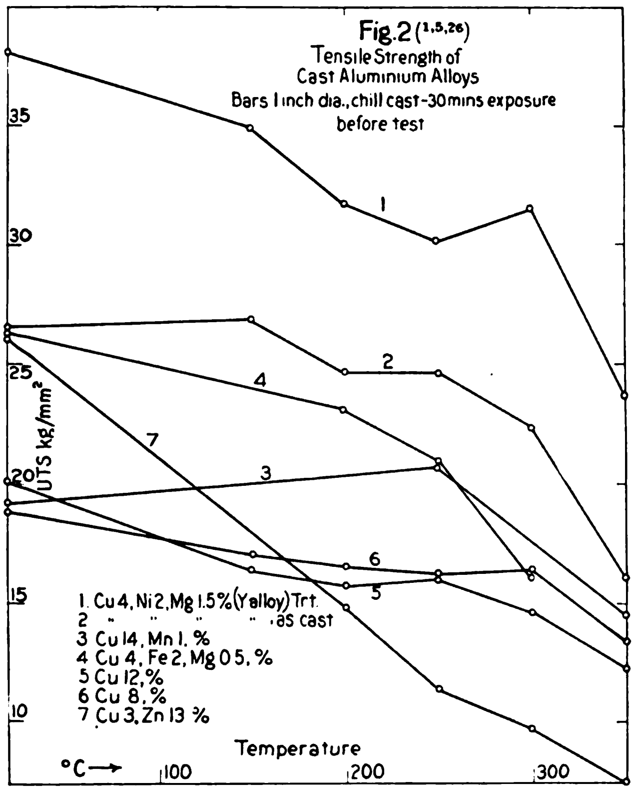
Fig.2 (1,5,26)
Tensile Strength of Cast Aluminium Alloys
Bars 1 inch dia., chill cast - 30 mins exposure before test
1. Cu 4, Ni 2, Mg 1.5% (Y alloy) Trt.
2 " " " " as cast
3 Cu 14, Mn 1. %
4 Cu 4, Fe 2, Mg 0.5, %
5 Cu 12, %
6 Cu 8, %
7 Cu 3, Zn 13 %
UTS kg/mm²
Temperature
°C →
35
30
25
20
15
10
100
200
300

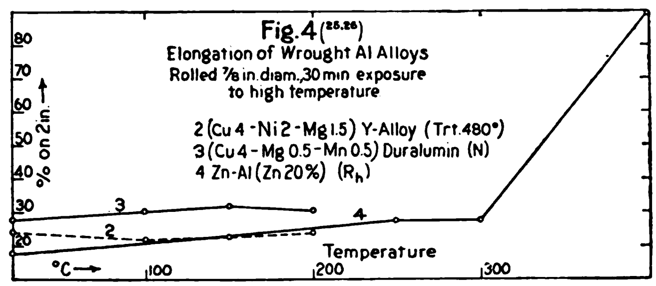
Fig.4 (25,26)
Elongation of Wrought Al Alloys
Rolled ⅞ in. diam., 30 min exposure to high temperature
2 (Cu 4 - Ni 2 - Mg 1.5) Y-Alloy (Trt. 480°)
3 (Cu 4 - Mg 0.5 - Mn 0.5) Duralumin (N)
4 Zn-Al (Zn 20%) (Rh)
% on 2 in. →
Temperature
°C →
80
70
60
50
40
30
20
100
200
300

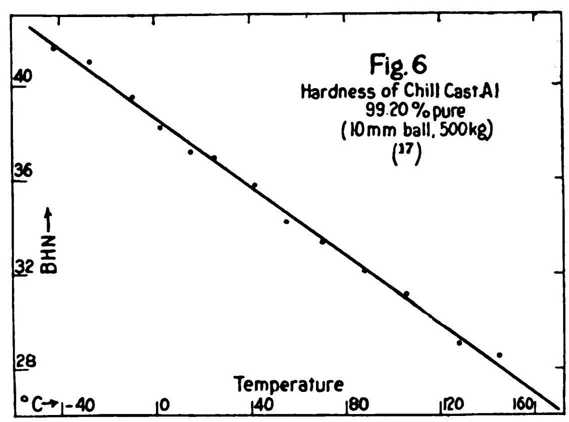
Fig.6
Hardness of Chill Cast Al
99.20% pure
(10 mm ball, 500 kg)
(17)
BHN →
Temperature
°C → -40
0
40
80
120
160
40
36
32
28

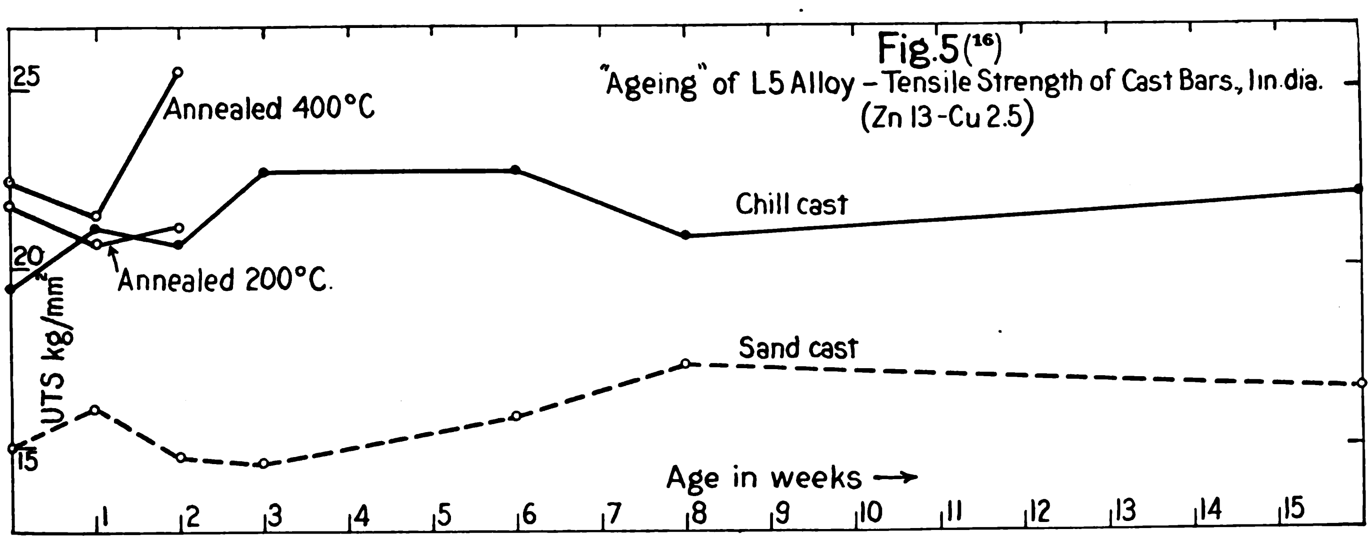
Fig.5 (16)
"Ageing" of L5 Alloy – Tensile Strength of Cast Bars, 1 in. dia.
(Zn 13 - Cu 2.5)
Annealed 400°C
Annealed 200°C.
Chill cast
Sand cast
UTS kg/mm²
Age in weeks →
25
20
15
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Al-Cu-Ni-Mg-Si.—(*Continued*)

Treatment	*UTS*	*YP*	*PL*	El_a	*RA*	Lit.
R_h, [illegible] in. diam	27.7	18.9		20	30	(23)
Same, Trt 530°	38.6	24.3	12.1	25	33	
Rivet, [illegible] in. diam., Trt 520°	40.3	24.7		25†	26	
Sheet: 0.05 in. thick, Trt 520°	41.0	27.1		19	PS‡	
Sheet: 0.05 in. thick, R_c, Trt 520°	42.4	25.2	15.4	18	27.6	
0.018 in. thick, R_c, Trt 520°	44.1	33.1		17	29.9	
0.064 in. Trt, A 350–400°	25.2	12.6		16		
Al, 90.9; Cu, 4.0; Ni, 2.12; Mg, 1.56; Fe, 0.42; Si, 1.03 "Y" alloy						
G_s 1 in. diam. bars	17.3		7.9	1.0		(1)
G_m 1 in. diam. bars	20.3		8.3	1.0		
Al, 92.3; Cu, 4.04; Ni, 1.77; Mg, 1.47; Fe, 0.20; Si, 0.20						
G_s 1 in. diam	17.3			2		(1)
G_m 1 in. diam	21.8			2		
Al, 88; Cu, 8.02; Ni, 1.98; Mg, 1.46; Fe, 0.20; Si, 0.20						
G_s 1 in. diam	16.85			0.5		(1)
G_m 1 in. diam	18.9			0.5		

* Nominal content.
† On 1 in.
‡ Stress at $\Delta l = \frac{1}{2}\% \, l_0$.

Al-Cu-Zn-Sn

% composition	Trt*	*UTS*	*YP*	*PL*	El_a	Lit.
Cu, 6.79; Zn, 0.96; Sn, 0.83; Fe, 0.25; Si, 0.20 "L 11"	G_s	11.0	5.5		3.0	(1)
	G_m	9.3	6.3		2.0	
Cu, 6–8; Zn, ⯈ 1.0; Sn, 0.5–2.0; Fe, ⯈ 1; Si, ⯈ 1 "L 11"	G_s	13.1		1.9	3.0	(1)
	G_m	13.1		2.4	3.0	
Cu, 9; Sn, 2.0; Zn, 1.5; Fe, ⯈ 1; Si, ⯈ 1	G_s	11.2			1	(1)
	G_m	17.3			3	

* Bars 1 in. diam.

Al-Mg-Si and Al-Mn

Nominal % composition	Treatment		*UTS*	*YP*	*PL*	*El**	*RA*	Lit.
Mg, 0.60; Si, 1.0	R, 75 % reduction	A	10.90	3.5	2.1	30.0		(11)
		Trt	34.50	24.6	11.2	18.0		
Mn, 1.2	R, 75 % reduction	A	12.30	4.9	2.1	40.0		(11)
		H	20.38	16.2	8.4	10.0		

* Gage length = 4 × diam.

Al-Zn(25)

Treatment* (diam. in.)	*UTS*	*YP*	El_a	*RA*
Zn, 5.21 %				
G_s, 1	8.2	4.25	16.0	
G_m, 1	10.4	4.4	29.0	
R_h, $\frac{5}{4}$	11.8	6.8	33	67
R_h, $\frac{7}{8}$	14.1	11.65†	26	66
A 400°	10.0	4.1	43	77
D_d, $\frac{13}{16}$	15.4	14.3†	19.5	65.8
Zn, 9.27 %				
G_s, 1	13.4	7.9	9.0	
G_m, 1	12.3	6.1	11.0	
R_h, $\frac{5}{4}$	14.8	7.7	36	70
R_h, $\frac{7}{8}$	16.35	10.1	33	67
R_h, $\frac{1}{2}$	17.6	11.0	38‡	68.3
D_d, $\frac{13}{16}$	17.5	15.4	19.0	56.5
D_d, $\frac{7}{90}$	25.7	23.1	7.5	
Zn, 11.0 %				
G_s, 1	14.8	10.1	8.0	
G_m, 1	16.1	7.9	16.0	
R_h, $\frac{7}{8}$	17.85	8.2	38	64
R_h, $\frac{1}{2}$	21.7	14.8	33‡	63.7
D_d, $\frac{7}{90}$	29.8	26.5	13.0	
Zn, 13.69 %				
G_m, 1	16.85	7.7	10.5	

Al-Zn(25).—(*Continued*)

Treatment* (diam. in.)	*UTS*	*YP*	El_a	*RA*
Zn, 13.24 %				
G_s, 1	16.7	13.4	4.0	
R_h, $\frac{5}{4}$	21.5	9.6	35	59
R_h, $\frac{7}{8}$	22.6	11.0†	31	52
A 400°	17.8	5.6	37	63.7
D_d, $\frac{13}{16}$	23.2	20.2†	19.0	43.5
Zn, 14.29 %				
G_m, 1	18.4	9.1	8.5	
Zn, 15.05 %				
G_s, 1	17.5	15.1	2.0	
R_h, $\frac{5}{4}$	25.8	10.7	33	53
R_h, $\frac{7}{8}$	26.05	13.4†	32	54
A 400°	21.0	6.7	37	60.4
R_h, $\frac{1}{2}$	28.2	18.3	31‡	58.5
D_d, $\frac{13}{16}$	26.0	17.5†	20	42.1
Zn, 16.08 %				
G_s, 1	20.0	17.3	3.5	
G_m, 1	18.0	8.35	6.5	
R_h, $\frac{7}{8}$	25.2	11.65	31	58
Zn, 16.85 %				
G_s, 1	19.1	16.1	1.0	
G_m, 1	21.4	9.1	5.0	
R_h, $\frac{5}{4}$	31.3	20.8	22	36
R_h, $\frac{7}{8}$	28.5	17.8†	25	45
D_d, $\frac{13}{16}$	30.9	27.4	13	24.5
Zn, 18.39 %				
G_m, 1	21.6	13.9	7.0	
Zn, 19.67 %				
G_s, 1	20.8	19.5	2.5	
R_h, $\frac{7}{8}$	31.9	19.5	21	47
R_h, $\frac{1}{2}$	34.4	25.6	30‡	54.7
D_d, $\frac{7}{90}$	40.4	24.8	9.0	
Zn, 20.15 %				
G_s, 1	20.6	15.75	1.0	
G_m, 1	21.7	12.3	4.0	
R_h, $\frac{5}{4}$	35.7	27.3	20	36
R_h, $\frac{7}{8}$	33.7	19.5†	26	46
A 400°	29.5	18.6	22	27.5
D_d, $\frac{13}{16}$	35.1	31.4†	13	26.5
Zn, 22.74 %				
G_m, 1	21.3	14.3	3.5	
Zn, 24.50 %				
G_s, 1	25.7		1.0	
R_h, $\frac{7}{8}$	39.0	31.2	20	39
R_h, $\frac{1}{2}$	37.8	32.0	27‡	46.6
D_d, $\frac{7}{90}$	42.4	38.1	7.0	
Zn, 26.05 %				
G_s, 1	27.3	17.6	2.0	
G_m, 1	27.9	16.7	4.0	
R_h, $\frac{5}{4}$	42.7	39.4	16	28
R_h, $\frac{7}{8}$	37.6	31.8†	20	41
D_d, $\frac{7}{90}$	42.2	34.7†	8.0	

% Zn	Treatment	*UTS*	*YP*	El_a
30.23	G_s 1 in. diam	26.1	12.8	1.5
	G_m 1 in. diam	28.2	16.2	3.0
36.02	G_s 1 in. diam	27.9	18.4	0.5
	G_m 1 in. diam	27.6	21.4	0.5

Al-Zn (25).—(*Continued*)

% Zn	Treatment	*UTS*	*YP*	El_a
40.27	G_s 1 in. diam........	28.8	18.3	1.0
	G_m 1 in. diam........	25.7	17.5	0.5
44.75	G_s 1 in. diam........	29.1	14.2	5.0
	G_m 1 in. diam........	30.1	15.3	1.0
49.66	G_s 1 in. diam........	29.5	20.5	4.0
	G_m 1 in. diam........	34.0	8.0	1.0

* Diameters after specified mechanical treatment given, test pieces 0.564 in. diam.

† *PL*'s of specimens are as follows:

Trt \ % Zn	5.21	13.24	15.05	16.85	20.15	26.05
R_h, 7/8 in.....	7.9	9.4	11.0	12.6	15.8	24.4
D_d, 11/16 in....	10.2	13.4	15.8		25.2	

‡ *El* on 1 in.

Al-Zn (24)

Sand cast 2 cm diam.			
% Zn	*UTS*	*PL*	*El*
10	11.0	4.4	7.5
20	14.2	5.0	2
31.6	17.8	5.0	1
40.6	21.4	12.9	1
50.7	19.5	13.7	0.5

Forged 2 cm diam. from 5 cm diam. G_m billets								
	As forged				Annealed 300°/1 h			
% Zn	*UTS*	*PL*	*El*	*RA*	*UTS*	*PL*	*El*	*RA*
5.3	12.9	10.9	19	64	9.1	2.4	30	74
10.2	17.2	10.1	34	55	14.0	4.3	38	65
16	23.9	17.2	23	47	21.9	7.1	28	41
21	29.6	21.1	14	27	29.8	10.7	15	37

Al-Zn-Cu (26)

Treatment	*UTS*	*YP*	El_a	*RA*
Zn, 3.50; Cu, 2.31				
G_s, 0.56 in. diam..........	13.7	6.3	12	
G_m, 1 in. diam...........	15.0	2.8	23	
R_h, 5/4 in. diam............	18.9	12.0	27	56.8
R_h, 7/8 in. diam............	17.3	10.4	29	61.6
Zn, 4.76; Cu, 0.87				
G_s, 0.56 in. diam..........	11.0	4.1	13	
G_m, 1 in. diam...........	12.6	4.25	25	
R_h, 5/4 in. diam............	16.4	9.9	29	64.0
R_h, 7/8 in. diam............	18.9	14.2	22	61.6
Zn, 4.71; Cu, 2.67				
G_s, 0.56 in. diam..........	13.5	3.9	7	
G_m, 1 in. diam...........	16.2	7.4	14	
R_h, 5/4 in. diam............	20.8	11.5	25	44.8
R_h, 7/8 in. diam............	18.6	11.5	26	50.8
Zn, 4.64; Cu, 3.92†				
G_s, 0.56 in. diam..........	12.9	7.25	4	
G_m, 1 in. diam...........	18.4	4.6	14	
R_h, 5/4 in. diam............	22.2	11.7	23	39.2
R_h, 7/8 in. diam............	20.9	13.2	20	42
Zn, 7.38; Cu, 1.76				
G_s, 0.56 in. diam..........	15.6	7.9	10	
G_m, 1 in. diam...........	15.9	5.2	19	
R_h, 5/4 in. diam............	20.5	12.8	25	64.0
R_h, 7/8 in. diam............	20.6	12.3*	30	57.2

Al-Zn-Cu (26).—(*Continued*)

Treatment	*UTS*	*YP*	El_a	*RA*
Zn, 9.91; Cu, 0.94				
G_s, 0.56 in. diam..........	16.2	9.1	8	
G_m, 1 in. diam.	16.9	7.4	19	
R_h, 5/4 in. diam............	20.5	9.5	29	59.2
R_h, 7/8 in. diam............	21.4	12.4*	24	50.8
Zn, 9.96; Cu, 2.75				
G_s, 0.56 in. diam..........	18.0	10.2	6	
G_m, 1 in. diam...........	20.2	7.6	11	
R_h, 5/4 in. diam............	26.3	15.0	23	39.2
R_h, 7/8 in. diam............	26.8	15.1*	24	42
Zn, 13.99; Cu, 1.64				
G_s, 0.56 in. diam..........	22.7	9.8	4	
G_m, 1 in. diam...........	23.9	9.9	16	
R_h, 5/4 in. diam............	33.7	17.0	23	36.4
R_h, 7/8 in. diam............	32.8	19.8	24	54.8
Zn, 14.74; Cu, 2.50				
G_s, 0.56 in. diam..........	22.2	15.3	3	
G_m, 1 in. diam...........	21.6	9.3	6.5	
R_h, 5/4 in. diam............	37.3	23.3	21	33.6
R_h, 7/8 in. diam............	33.1	19.8*	20	36.4
Zn, 18.45; Cu, 0.80‡				
G_s, 0.56 in. diam..........	23.1	11.7	4	
G_m, 1 in. diam...........	22.4	13.1	2	
R_h, 5/4 in. diam............	38.9	30.1	22	39.2
R_h, 7/8 in. diam............	38.1	26.0*	24	39.2
Zn, 18.95; Cu, 1.66				
G_s, 0.56 in. diam..........	25.4	18.3	3	
G_m, 1 in. diam...........	29.1	12.8	11	
R_h, 5/4 in. diam............	39.9	32.9	21	39.2
R_h, 7/8 in. diam............	38.1	25.8*	24	36.4
Zn, 23.48; Cu, 2.67				
G_s, 0.56 in. diam..........	28.7	8.8	2	
G_m, 1 in. diam...........	31.8	10.1	4	
R_h, 5/4 in. diam............				
R_h, 7/8 in. diam............	46.6	31.7	18	33.5

* Values of *PL* are:

% Zn.........	7.38	9.91	9.96	14.74	18.45	18.95
% Cu.........	1.76	0.94	2.75	2.50	0.80	1.66
PL...........	8.7	12.6	13.7	18.9	20.6	1.92

† Contains also Fe, 0.10; Si, 0.14.
‡ Contains also Fe, 0.16; Si, 0.12.

Commercial Al-Zn-Cu

% composition	Treatment	*UTS*	*YP*	*PL*	El_a	Lit.
Al, 80.5–85; Zn, 12.5–14.5; Cu, 2.5–3, "L 5" alloy						
Zn, 12.5–14.5; Cu, 2.5–3; Fe, ≯ 1; Si, ≯ 1 (*v.* Fig. 5)	G_s, 1 in. diam.	16.5		2.8	2	(1)
	G_s new, 3/4 in. diam. 22 tests (12 melts)	17.3–23.3			2–4	(5)
		20.6 (mean)			3	(5)
	G_m, 1 in. diam.	19.4		4.4	4	(1)
	G_m new, 3/4 in. diam. 24 tests (12 melts)	18.3–23.3			4–7	(5)
		20.8 (mean)			5.0	(5)
Zn, 12.58; Cu, 2.69*	G_s new, 1 in. diam. (for max. *IS*)	19.1			5	(1)
	G_m new, 1 in. diam. (for max. *IS*)	18.7			7	
Zn, 13.5; Cu, 2.5*†	G_s new, 1 in. diam.	16.5	7.1		4.0	(23)
	G_m new, 1 in. diam.	20.5	7.1		5.0	

Commercial Al-Zn-Cu.—(*Continued*)

% composition	Treatment	*UTS*	*YP*	*PL*	El_a	Lit.
Al, 77; Zn, 20; Cu, 3 "A" alloy						
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20	R_h, 1½ in. diam.	42.5	28.4	19.5	17‡	(23)
	Same, A 200°C	39.1	23.6		21	
	R_h, ¾ in. diam.	42.5	28.8		21§	
	R_h, 0.104–0.048 in. thick	42.8	26.6	*PS*‖ = 28–33	19	
	Same, A 200°C	35.0	19.4		26	
	R_c, 0.104–0.048 in. thick	46.8	41.0		11	
	D, 0.063 in. diam.	43.8			8	
	Same, A 250°	32.6			14_c	
	D, 0.0125 in. diam.	43.0			2	
	Same, A 250°	32.6				
	G_s, 5 in. diam. E, 2½ in. diam.	43.6	28.8		19	
	G_s, 5 in. diam. E, 1½ in. diam.	41.1	24.9		22	
Zn, 20.52; Cu, 3.13	R_h, ¾ in. diam.	43.0	27.1		17	(26)
	R(rod) C(−80°/10 m) J	46.2	29.8		13.0	

* Contains Fe, 0.20; Si, 0.20.
† Nominal composition.
‡ *RA* = 30 %.
§ *RA* = 36 %.
‖ Δl = ½ % l_0.

Al-Zn-Cu-Fe and Al-Zn-Cu-Mg-Mn

Treatment	*UTS*	*YP*	*PL*	El_a	*RA*	Lit.
Al, 86.5; Zn, 10.0; Cu, 2.0; Fe, 1.5 (nominal)						
G_s, 2 × ½ in. diam	19.1	8.5*	4.9	4.0		(11)
Al; Zn, 18; Cu, 2.5; Mg, 0.35; Mn, 0.35† "G" alloy						
R_h, 0.04–0.05 in. thick 400° Q	54.5	48.2	38–39.5*	19		(23)
E, 4 × ¾ in. R_h, same	52.0	40.2		17		
Al; Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5 "E" alloy‡						
R_h, ¾ in. diam	46.8	37.3		15		(23)
Same, 350° Q	59.6	51.8	34.8	12	13.4	
E, ½ in., R_h, ¾ in., 400° Q	64.1	34.0		9		
R_h, 0.04–0.05 in. thick	51.0	38.6		18		
Same, A 250°	39.8	22.8		20		
Same, 400° Q	60.2	46.2	44–49*	15		
E, ½ in., R_h, 0.04–0.05 in., 400°Q	61.4	31.5		12		
R (rod) C(−80°/10 m) J	69.0	55.8		13.0		(27)
R_h, ¾ in. diam. (400° Q, "F" alloy†)	56.7	38.9		16	21.4	(24)
R_h, 0.04–0.05 in. thick (400° Q, "F" alloy†)	55.8	47.9	39–44*	19		
E, 4 × ¾ in., same (400° Q, "F" alloy†)	52.8	45.7		15		

* Stress to produce set of ½ % l_0.
† Contains also Fe, 0.20; Si, 0.75, otherwise similar to "E" alloy.
‡ Contains Fe, 0.20; Si, 0.20.

Table 2.—Compression Tests

% composition*	Treatment†	*UCS*	PL_C	Lit.
Al, 99.24	R, ¾ in.	18.00	8.0	(22)
Al, 99.20	R_d, 75%	ca. 16	*YP* ca. 13	(11)
	R, 75% A	ca. 10	*YP* ca. 3	
Al(% = ?)	G	47		(6)
Cu, 8 "L 11"	G_s	49		(11)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R, ½–1, N	35.2	14.66	(21)
	Same, 495° QV‡	35.2	12.15	
	370°/20 C_t	18.7	4.82	
Duralumin§	R, 1 in. sq.	*CS* = 50.4; Δl = −14% l_0		(23)

% composition*	Treatment†	*UCS*	YP_C	Lit.
Zn, 9.27	R_h, ¾ in.	13.95	11.5	(25)
Zn, 11.0	G_s, 1 in.		12.6	(25)
	R_h, ¾ in.	14.5	10.2	

Table 2.—Compression Tests.—(*Continued*)

% composition*	Treatment†	*UCS*	YP_C	Lit.
Zn, 14.29	G_s, 1 in.		16.1	(25)
Zn, 15.05	R_h, ¾ in.	19.4	14.3	(25)
Zn, 16.08	G_s, 1 in.	25.5	21.7	(25)
	G_m, 1 in.	18.9	14.0	
	R_h, ¾ in.	24.3	17.2	
Zn, 19.67	G_m, 1 in.	28.5	23.9	(25)
	R_h, ¾ in.	28.9	25.7	
Zn, 20.15	G_s, 1 in.	28.7	26.2	(25)
Zn, 22.74	G_m, 1 in.	26.8	23.3	(25)
Zn, 24.50	G_s, 1 in.	31.0	28.2	(25)
	R_h, ¾ in.	36.7	33.2	
Zn, 30.23	G_m, 1 in.	31.3	26.6	(25)
Zn, 40.27	G_m, 1 in.	32.9	31.8	(25)
Zn, 44.75	G_m, 1 in.	38.0	29.8	(25)
Zn, 55.07	G_s, 1 in.	30.9	29.8	(25)
	G_m, 1 in.	37.2	36.2	
Zn, 10; Cu, 2; Fe, 1.5	G_s (new)	66		(11)
			PL_C	
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20 "A"	R_h, 1¾ in.	20.8‖	15.0	(23)
	E, ¾, R_h, ¾ in.	23.0‖	18.1	
	E, 1¼ in.	19.5‖	14.2	
	E, 2 in.	¶	14.9	

* % Al by difference.
† Dimensions are diameters, unless marked otherwise.
‡ W 495°/30 Q_b V.
§ Cu, 3.5–4.5; Mn, 0.4–0.7; Mg, 0.4–0.7; Fe, 0.75, Si, 0.60.
‖ Test pieces 2.75 in. × 0.5 in. diam.
¶ Length ≯ 4 × diam.

Table 3.—Shear and Torsion Tests

% composition*	Treatment†	*USS*	PL_S‡	Lit.
Al, 99.24	R, ¾ in.	9.7		(22)
Al, 99.20	Wk_d, 75%	7.7		(11)
	Same, A	7.0		
Al (% = ?)	G	8.4		(6)
	R	11.2		
Cu, 3.25; Mg, 0.70; Mn, Tr.; Fe, 0.28; Si, 0.28	R, ½–1, N	20.5		(21)
		30.4§	13.3	
	RW 495°/30 Q_b 2 h V	18.7		
		33.2§	9.9	
	RW 370°/20 C_t	11.4		
		19.0§	5.5	
Cu, 4.5; Mn, 0.70; Si, 0.80	Wk, A	11.2		(11)
	Wk, Trt	25.3		
Cu, 3.85; Mg, 0.8; Mn, 0.4; Fe, 0.5; Si, 0.9; Zn, 0.04	G_m, 3.5 mm‖	15.4		(15)
	Same, Trt‖	22.4		
	G_s, 42 mm Trt	24.3		
Duralumin ¶	Wk	30.0		(9)
Duralumin**	D, ⅛ in.	25.9		(23)
Mg, 0.60; Si, 1.0	Wk, A	7.7		(11)
	Wk, Trt	23.2		
Mn, 1.2	Wk, A	9.1		(11)
	Wk, H	10.5		
Zn, 9.27	R_h, 1¼ in.	16.3‡		(25)
11.0		19.5‡		
15.05		22.8‡		
16.08		32.5‡		
Zn, 24.50	R_h, 1¼ in.	32.5‡		[illegible]

TABLE 3.—SHEAR AND TORSION TESTS.—(*Continued*)

% composition*	Treatment†	*USS*	PL_s‡	Lit.
Zn, 10	G_s, 2 cm	6.05		(24)
20		9.0		
31.6		10.1		
40.6		10.4		
50.7		9.9		
Zn, 13.5; Cu, 2.5††	G_m, 1 in.	20.2‡‡		(23)
Zn, 20; Cu, 3; Fe, 0.20; Si, 0.20; "A" alloy	R_h, 1¾ in.	34.2‡	9.46	(23)
	R_h, 0.046 in.‖	34.5‡‡		
	R_h, 0.061 in.‖	36.7‡‡		
	D_d, 0.063 in.	27.3		
	Same, A 250°	27.7		

* % Al by difference.
† Dimensions are diameters unless marked otherwise.
‡ From torsion test.
§ Torsional modulus of rupture.
‖ Thickness.
¶ Alloy 681 A: Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.
** Rivet wire: Cu, 3.92; Mn, 0.51; Mg, 0.37; Fe, 0.36; Si, 0.41.
†† Contains Fe, 0.2; Si, 0.2.
‡‡ Punching test.

TABLE 4.—HARDNESS

% composition*	Treatment†	*BHN*	*d-P*‡	*ScH*§	Lit.
Al, 99.97	Wk, A	16	B		(10)
Al, 99.24; Fe, 0.5; Cu; Si	R, ¾ in.	45	B		(22)
Al, 99.20	G_s, ½ in.	23	B		(11)
	Wk_d, 75 %	39	B	17	
	Same, A	25	B	6	
Al, ≮99.00	G_s	21–24	B	6–9	(6)
	Sheet, A	22–26	B	4–6	
Al, 99.07–98.46; Fe, 0.70–0.98; Si, 0.23–0.56	10 mm‖ A	25	B		(14)
	Same, Wk_c 150–200 %	41	B		
	1 mm‖ A			4.5	
	Same, Wk_c 50 %			16	
	Same, Wk_c 300 %			28	
	2 mm‖ A			5.5	
	Same, Wk_c 50 %			11.5	
	Same, Wk_c 300 %			16	
Cu, 4.0 (nom.)	G_s, ½ in.	70–75	B		(11)
Cu, 4.5; Fe, 0.20; Si, 0.20 (nominal)	G_s 1 in. V 8 mo.	46	B		(23)
	G_m 1 in. V 8 mo.	49	B		(23)
	RW 510° Q Tp 160°¶	100	B		(16)
Cu, 8.00 "L 11"	G_s, ½ in.	65	B		(11)
Cu, 11–13 "L 8"**	G_s, 1 in.	67–91	B		(1)
	G_m, 1 in.	80–84	B		
Cu, 12.48 "L 8" ††	G_s, 1 in.	81	B	*LCH*	(1)
	G_m, 1 in.	67, 74	B	87, 94	
Cu, 4.0; Mg, 0.5 (nom); Fe, 0.20	G_s, 1 in.	55	B		(1)
				ScH§	
Cu, 3.5; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R ½–1, N	100	B	19	(21)
	495° Q_b V	100	B	22	
	370° C_f	50	B	12	
Cu, 4.5; Mn, 0.7; Si, 0.8	Wk, A	43	B	15	(11)
	Wk, Trt	95	B	30	
Duralumin‡‡	7 mm‖ "H"	98	D		(9)
	Same, "681 D"	125	D		
Duralumin§§	10 mm‖ 475° Q	85	A		(14)
	10 mm‖ A 350°	45	B		
Cu, 4.0; Ni, 2.0; Mg, 1.5; Fe, 0.20; Si, 0.20 "Y" alloy	G_s, 1 in.	88, 91	B		(23)
	Same, Trt	107	B		
	G_m, 1 in.	83, 88	B		
	Same, Trt	102–106	B		
	R_h, ¾ in., Trt	96‖‖	B		
	in.‖, Trt	109‖‖	E		
Cu, 4.0; Ni, 2.12; Mg, 1.56; Fe, 0.42; Si, 1.03 "Y" alloy	G_s, 1 in.	70, 73			(1)
	Same, J 200°	60, 62			
	Same, J 300°	45, 47			
	Same, J 400°	17, 17			
	G_m, 1 in.	76			
	Same, J 200°	65, 70			
	Same, J 300°	49, 57			

TABLE 4.—HARDNESS.—(*Continued*)

% composition*	Treatment†	*BHN*	*d-P*‡	*LCH*	Lit.
Cu, 6.8; Zn, 1.0; Sn, 0.8†† "L 11"	G_s, 1 in.	60	B	65	(1)
	G_m, 1 in.	44	B		
Cu, 6–8; Zn, ≯ 1; Sn, ½–2** "L 11"	G_s, 1 in.	50–55	B		(1)
	G_m, 1 in.	48–60	B	*ScH*§	
Mg, 0.6; Si, 1.0 (nominal)	R, 75 % A	27.0	B	9	(11)
	R, 75 % Trt	96.0	B	33	
Mn, 1.2 (nominal)	R, 75 % A	32.0	B	10	(11)
	R, 75 % H	50.0	B	20	
Zn, 5.21	R_h, 1¼in.	35	C	5.0	(28)
9.27	R_h, 1¼in.	56	C	6.7	
13.24	R_h, 1¼in.	62	C	9.1	
Zn, 15.05	R_h, 1¼in.	88	C		(25)
16.85	R_h, 1¼in.	105	C	15.0	
20.15	R_h, 1¼in.	162	C	18.0	
24.50	R_h, 1¼in.	156	C	25.0	
Zn, 10	G_s, 20 cm	40	A	10.3	(24)
20	G_s, 20 cm	81	A	32	
31.6	G_s, 20 cm	85	A	30.5	
40.6	G_s, 20 cm	85	A	34.8	
50.7	G_s, 20 cm	78	A	36.8	

Zn	Cu	Treatment†	*BHN*	*d-P*‡	*LCH*	Lit.
3.5	2.31	R_h, 1 ¼ in.	53.1	C	6.2	(26)
4.76	0.87	R_h, 1 ¼ in.	48.3	C	6.3	
4.71	2.67	R_h, 1 ¼ in.	62.2	C	9.5	
4.64	3.92	R_h, 1 ¼ in.	65.2	C	7.6	
7.38	1.76	R_h, 1 ¼ in.	63.5	C	6.5	
9.91	0.94	R_h, 1 ¼ in.	51.5	C	7.3	
9.96	2.75	R_h, 1 ¼ in.	87.8	C	10.7	
14.0	1.64	R_h, 1 ¼ in.	91.7	C	12.3	
14.74	2.5	R_h, 1 ¼ in.	98.4	C	16.5	
18.45	0.8	R_h, 1 ¼ in.	118.7	C	18.7	
18.95	1.66	R_h, 1 ¼ in.	120.0	C	19.6	

% composition*	Treatment†	*BHN*	*d-P*‡	*LCH*	Lit.
Zn, 12.5–14.5; Cu, 2.5–3** "L 5"	G_s, 1 in.	70, 80	B		(1)
	G_m, 1 in.	60–85	B	*LCH*	
Zn, 12.58; Cu, 2.69†† "L 5"	G_m, 1 in.	68	B	77	(1)
	G_s, V 7 yr¶¶	88	B		(23)
	Same, Tp 350°	64	B		(23)
Zn, 13.5; Cu, 3.5†† "L 5"	G_s 1 in. new	68	B		(23)
	G_m 1 in. new	64	B		
Zn, 20; Cu, 3 ††	R_h, 1¾ in.	114	B		(23)
Zn, 10; Cu, 2; Mg, 1.5 (nom.)	G_s, ½ in.	70	B		(11)

* % Al by difference.
† Dimensions are diameters unless otherwise indicated.
‡ Ball diameters and loads are as follows: A = 10 mm, 1000 kg; B = 10 mm, 500 kg; C = 9.52 mm, 1000 kg; D = 2.5 mm, 62.5 kg; E = 2 mm, 40 kg.
§ Magnifier hammer used.
‖ Thickness.
¶ R_h, 1¾ in. diam., W 510°/1 da, Q V 2 d, Tp 160°/20 h.
** Contains Fe, ≯1; Si, ≯1.
†† Contains Fe, 0.2; Si, 0.2.
‡‡ Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.
§§ Cu, 3.5–4; Mn, 0.5–1; Mg, 0.5.
‖‖ Treated at 520°.
¶¶ ½ in. sq. Tp = W 350°/30 C_s.

TABLE 5.—IMPACT HARDNESS (1)

% composition	Name	Trt	*IHN** Cone	*IHN** 10 mm ball
Cu, 12.48; Fe, 0.20; Si, 0.20	L 8	G_s	98–101	103–107
		G_m	100	105–118
Cu, 4.0; Fe, 2.0; Mg, 1.5†		G_s	113	117
Cu, 6.79; Zn, 0.96; Sn, 0.83; Fe, 0.20; Si, 0.20	L 11	G_s	70–79	69–72
		G_m	73	69
Zn, 12.58; Cu, 2.69; Fe, 0.20; Si, 0.20	L 5	G_s	99	103
		G_m	91	81

* *IHN* = energy of blow (kg-m) ÷ volume of indentation (cm^3).
† Nominal.

TABLE 6.—IMPACT STRENGTH

% composition*	Treatment†	IS‡ (kg-m)	Lit.
Al, 99.67; Fe, 0.06; Si, 0.25	J { 20° − 20° − 80° − 182°	$11.2_{y'}$ $10.6_{y'}$ $11.2_{y'}$ $13.1_{y'}$	(6)
Al, 99.24	R, ¾ in.	32.3_u	(22)
Al, 99.1–98.4; Fe, 0.7–1; Si, 0.2–0.56	10 mm thick A Same, Wk_c { 50 % 300 %	$8–8.5_y$ 5.2_y 5.0_y	(14)
Cu, 5.7; Fe, 0.2; Si, 0.2	G_s, 1 in. G_m, 1 in.	0.058_v $.146_v$	(1)
Cu, 7.75; Fe, 0.2; Si, 0.2 "L 11"	G_s, 1 in. G_m, 1 in.	0.028_v $.095_v$	(1)
Cu, 11–13; Fe, ≯ 1; Si, ≯ 1 "L 8"	G_s, 1 in. G_m, 1 in.	0.087_u $.090_u$	(1)
Cu, 12.5; Fe, 0.2; Si, 0.2 "L 8"	G_s, 1 in. G_m, 1 in.	0.012_v $.033_v$	(1)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28	R ½–1, N 495°, 100° Q 370°/20 C_f	1.92_z 2.68_z 2.39_z	(21)
Cu, 2.1; Mn, 1.9	R_h, ⅞ in.	0.57_u	(27)
Cu, 2.9; Mn, 0.9	R_h, ⅞ in.	0.76_u	(27)
Cu, 14.1; Mn, 0.9; Fe, 0.2; Si, 0.2	G_s, 1 in. G_s, 1 in.	0.008_v $.016_v$	(1)
Cu, 3.5–4; Mg, 0.5; Mn, 0.5–1 "Duralumin"	10 mm thick { 475° Q 475° Q_2 A 350°	3.2_y 3.6_y 4.0_y	(14)
Cu, 3.6; Mg, 0.5; Mn, 0.5; Fe, 0.6; Si, 0.6 "Duralumin"	J { 20° − 20° − 80° − 182°	$5.0_{y'}$ $5.6_{y'}$ $5.0_{y'}$ $5.6_{y'}$	(6)
Cu, 3; Mn, 1; Mg, 0.5; Fe‖; Si, 1§	R, ⅞ in. Trt J { 20° 150°	$0.76_v–0.70_w$ $0.67_v–0.68_w$	(23)
Cu, 5.08; Mn, 0.4; Mg, 0.85; Fe, 0.2; Si, 0.89§	R_h, ⅞ in. Trt J { 20° 150° 240°	$0.43_v–0.33_w–1.78_x$ $0.37_v–0.30_w$ $0.20_v–0.15_w$	(23)
Cu, 6.25; Mn, 0.47; Mg, 0.79; Fe‖; Si, 1.17§	R_h, ⅞ in. Trt J { 20° 150° 240°	$0.32_v–0.23_w–1.24_x$ $0.30_v–0.24_w$ $0.16_v–0.11_w$	(23)
Cu, 2; Ni, 1.47; Mg, 0.95; Mn, 0.4; Fe‖; Si, 0.75¶	R_h, ⅞ in. Trt J { 20° 150° 240°	$0.39_v–0.27_w–1.65_x$ $0.35_v–0.25_w$ $0.17_v–0.13_w$	(23)
Cu, 4.0; Ni, 1.77; Mg, 1.47** "Y"	G_s, 1 in. G_m, 1 in.	0.017_v 0.042_v	(1)
Cu, 4; Ni, 2; Mg, 1.5**	G_m, Trt	0.50_u	(23)
Cu, 4.08; Ni, 2.03; Mg, 1.60; Fe‖; Si, 0.25 "Y"	R_h, ⅞ in. Trt J { 20° 150° 240°	$0.26_v–0.22_w–1.20_x$ $0.24_v–0.17_w$ $0.15_v–0.11_w$	(23)
Cu, 4.22; Ni, 2.05; Mg, 0.52; Mn, 0.4; Fe; Si††	R_h, ⅞ in. Trt J { 20° 150° 240°	0.26v–$0.20_w–1.16_x$ $0.27_v–0.18_w$ $0.21_v–0.16_w$	(23)
Cu, 4.35; Ni, 1.77; Mg, 1.59; Mn, 0.4; Fe; Si‡‡	R_h, ⅞ in. Trt J { 20° 150° 240°	$0.24_v–0.18_w–1.05_x$ $0.19_v–0.16_w$ $0.13_v–0.09_w$	(23)
Cu, 8; Ni, 2; Mg, 1.46**	G_s, 1 in. G_m, 1 in.	0.009_v 0.013_v	(1)
Cu, 9; Sn, 2; Zn, 1.5§§	G_s, 1 in. G_m, 1 in.	0.18_u 0.25_u	(1)
Cu, 6.8; Zn, 0.96; Sn, 0.83** "L 11"	G_s, 1 in. G_m, 1 in.	0.051_v 0.082_v	(1)
Cu, 6–8; Zn, ≯ 1; Sn, 0.5–2 "L 11"	G_s, 1 in. G_m, 1 in.	0.28_u 0.29_u	(1)
Zn, 5.21	R_h, ⅞ in.	0.56_u	(25)
9.27	R_h, ⅞ in.	$.60_u$	
13.24	R_h, ⅞ in.	$.75_u$	
15.05	R_h, ⅞ in.	$.80_u$	
16.85	R_h, ⅞ in.	$.80_u$	
20.15	R_h, ⅞ in.	$.80_u$	
26.05	R_h, ⅞ in.	$.57_u$	
Zn, 15	J { 20° − 20° − 80° − 180°	$11.2_{y'}$ $11.2_{y'}$ $10.0_{y'}$ $9.3_{y'}$	(6)
Zn, 30	J { 20° − 20° − 80° − 180°	$2.5_{y'}$ $2.5_{y'}$ $1.9_{y'}$ $1.8_{y'}$	(6)
Zn, 12.6; Cu, 2.7; Fe; Si** "L 5"	G_s, 1 in. G_m, 1 in.	0.146_v 0.200_v	(1)
Zn, 12.5–14.5; Cu, 2.5–3§§ "L 5"	G_s, 1 in. G_m, 1 in.	0.43_u‖‖ 0.57_u‖‖	(1)
Zn, 20.3; Cu, 2.9; Fe-Si** "A"	R, ⅞ in. Trt J { 20° 150°	$0.53_v–0.47_w$ 0.66_v	(23)
Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5 "E"	R, ⅞ in. Trt J { 20° 150°	$0.31_v–0.30_w$ $0.44_v–0.36_w$	(23)
Zn, 15.0; Pb, 1.5	J { 20° − 20° − 80° − 182°	$10.0_{y'}$ $10.0_{y'}$ $10.0_{y'}$ $8.1_{y'}$	(6)

* % Al by difference.
† Dimensions are diameters unless otherwise marked.
‡ Meaning of subscripts (C. S. = Cross section of specimens):

Subscript	Machine	C. S., mm	Notch	Depth, mm	Radius, mm
u	Izod				
v	Charpy	5 × 5	90° V	1	2.3
w	Charpy	5 × 5	45° V	1	0.25
x	Charpy	10 × 10	45° V	2	0.25
y	Charpy	10 × 10	Mesnager	2	1
y′	Guillery	10 × 10	Mesnager	2	1
z	Charpy	10 × 10	USN	5	1

§ Duralumin type.
‖ Fe 0.2.
¶ Magnalite type.
** Fe, 0.2; Si, 0.2.
†† Fe, 0.2; Si, 0.79.
‡‡ Fe, 0.2; Si, 0.25.
§§ Fe, ≯1; Si, ≯1.
‖‖ Unbroken.

TABLE 7.—ELASTIC PROPERTIES

% composition	Treatment*	10^{-3} E	Lit.
Al, 99.24	R, ¾ in.	71	(22)
Al, 99.20	R_d, 75% Same, A	70 70	(11)
Al (% = ?)	R or D	68.9	(6)
Cu, 11–13† "L 8"	G_s, 1 in. Same, J 250° G_m, 1 in.	75–83 57–64 75–84	(1)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.18; Si, 0.28	R, ½–1, N 495° Q_b V 370° C_f	71.2 76.9 75.5	(19)
Cu, 2.1; Mn, 1.9	R_h, ⅞ in.	73.1	(27)
Cu, 2.9; Mn, 0.9	R_h, ⅞ in.	75.6	(27)
Cu, 4.5; Mn, 0.7; Si, 0.8	Wk	70	(11)
Cu-Mn-Mg‡ "Duralumin"	Wk	70.3	(23)
Cu, 4; Ni, 2; Mg, 1.5§ "Y"	G_m R_h R_h } Trt 520°	76‖ 74¶ 75‡‡	(23)
Cu, 4; Ni, 2.1; Mg, 1.56; Fe, 0.4; Si, 1.0 "Y"	G_s, 1 in. Same, J 250° G_m, 1 in. Same, J 250°	74.5 71 76.6 74.5	(1)
Cu, 6–8; Zn, ≯1; Sn, 0.5–2.0† "L 11"	G_s, 1 in. G_m, 1 in.	68 64	(1)
Zn, 5.21	R_h, ⅞ in. D_c, 1⅜ in.	63.7 63.7	[illegible]

TABLE 7.—ELASTIC PROPERTIES.—(*Continued*)

% composition	Treatment*	$10^{-2}E$	Lit.
Zn, 13.24	R_h, $\frac{7}{8}$ in.	63.7	(25)
	D_c, $\frac{13}{16}$ in.	63.5	
Zn, 15.05	R_h, $\frac{7}{8}$ in.	69.4	(25)
	D_c, $\frac{13}{16}$ in.	62.1	
Zn, 16.85	R_h, $\frac{7}{8}$ in.	63.1	(25)
Zn, 20.15	R_h, $\frac{7}{8}$ in.	63.1	(25)
	D_c, $\frac{13}{16}$ in.	63.1	
Zn, 26.05	R_h, $\frac{7}{8}$ in.	61.9	(25)
Zn, 7.38; Cu, 1.76	R_h, $\frac{7}{8}$ in.	70.3	(26)
	D_c, $\frac{13}{16}$ in.	69.4	
Zn, 9.91; Cu, 0.94	R_h, $\frac{7}{8}$ in.	67.9	(26)
	D_c, $\frac{13}{16}$ in.	68.4	
Zn, 9.96; Cu, 2.75	R_h, $\frac{7}{8}$ in.	68.4	(26)
	D_c, $\frac{13}{16}$ in.	66.4	
Zn, 12.5–14.5; Cu, 2.5–3† "L 5"	G_s, 1 in.	68	(1)
	G_m, 1 in.	68	
Zn, 14.74; Cu, 2.50	R_h, $\frac{7}{8}$ in.	68.4	(26)
Zn, 18.45; Cu, 0.80	R_h, $\frac{7}{8}$ in.	67.2	(26)
	D_c, $\frac{13}{16}$ in.	66.8	
Zn, 18.95; Cu, 1.66	R_h, $\frac{7}{8}$ in.	67.9	(26)
Zn, 20; Cu, 3† "A"	R_h, $1\frac{5}{8}$ in.	68	(23)
Zn, 20; Cu, 2.5§; Mn, Mg†† "E"	ER_h, $\frac{7}{8}$ in. 350° Q V	69	(23)

% composition	Treatment*	$10^{-2}G$	Lit.
Al, 99.24	R, $\frac{3}{4}$ in.	24.2	(22)
Al (% = ?)	G	25.8	(6)
Cu-Mn-Mg,** "Duralumin"	Bar, 1 in. sq.	28	(23)
Cu, 3.25; Mg, 0.7; Mn, Tr.; Fe, 0.28; Si, 0.28.	R, $\frac{1}{2}$– 1, N	27.0	(19)
	495° Q_o V	27.0	
	370° C_f	27.0	
Zn, 20; Cu, 3§ "A"	R_h, $1\frac{5}{8}$ in.	26.4	(24)

* Dimensions are diameters.
† Contains Fe, ≯1; Si, ≯1.
‡ Cu, 3.5–5.5; Mn, 0.5–0.8; Mg, 0.5.
§ Contains Fe, 0.20; Si, 0.20 (nominal).
‖ 1 in. diam.
¶ $\frac{7}{8}$ in. diam.
** Cu, 3.5–4.5; Mn, 0.4–0.7; Mg, 0.4–0.7.
†† Each 0.5 %.
‡‡ Sheet, $\frac{1}{2}$ in. thick.

TABLE 8.—SPECIFIC GRAVITY

Al (Commercial)*

% composition†	Treatment‡	d_4^t	Lit.
Al, 99.64; Fe, 0.15; Si, 0.21	G_m, 4 in. sq.	2.703	(3)
	R_c, 2–0.02 in.§	2.709	
	Same, A 450°/14 h	2.710	
	D_c, wire	2.703	
	Same, A	2.706	
Al, 99.50	D_d, No. 10 SWG	2.703‖	(12)
	Same, A	2.705‖	
Al, 99.37; Fe, 0.28; Si, 0.35	D_c, 0.064 in.	2.702	(3)
	D_c, A	2.705	
Al, 99.33; Fe, 0.38; Si, 0.29	R_c, 0.080 in. thick	2.708	(3)
	Same, A	2.709	
Al, 99.25	G	2.727‖	(12)
	Liq., 658.7°C	2.405‖	
	Liq., 1000°C	2.311‖	
Al, 99.11; Fe, 0.56; Si, 0.33	G_m, 4 in. sq.	2.706	(3)

Chill Cast¶ Commercial Alloys (18, 23)

% composition	Name	d_4^{20}
Cu, 11–13; Fe, ≯ 1; Si, ≯ 1	L 8	2.83–2.94
Cu, 4; Fe, 2; Mg, 0.5 (nominal)		2.80
Cu, 14; Mn, 1.0; Fe, 0.2; Si, 0.2 (nominal)		2.98
Cu, 4; Ni, 2; Mg, 1.5; Fe, 0.2; Si, 0.2	Y	2.79
Cu, 6–8; Zn, ≯ 1; Sn, 0.5–2**	L 11	2.87–2.93
Zn, 12.5–14.5; Cu, 2.5–3**	L 5	3.0

Al-Cu (7)

% Cu \ Trt	G_s¶	G_m¶	R_h††	D_c††
0.86	2.72	2.73	2.73	2.73
1.90	2.73	2.75	2.75	2.75
2.77	2.75	2.77	2.77	2.77
3.76	2.77	2.79	2.79	2.79
4.97	2.78	2.81	2.81	
6.15	2.81	2.83	2.83	*v. also* p. 576.
6.91	2.82	2.85	2.85	
8.08	2.85	2.88	2.88	

Al-Zn (25)

% Zn \ Trt	G_s‡‡	G_m¶	R_h§§	D_d††
5.21	2.737	2.783	2.800	2.800
9.27	2.810	2.848	2.867	2.868
13.69		2.910	2.944	2.940
13.24	2.914			
14.29		2.956	2.987	2.985
15.05	2.956			
16.85	2.973	3.017	3.029	3.035
20.15	3.061	3.082	3.093	3.088
26.05	3.176	3.208	3.241	
30.23	3.283	3.352		
36.02	3.325	3.424		
40.27	3.414	3.627		
44.75	3.621	3.753		
49.66	3.906	3.920		

Al-Cu-Mn (27)

% Cu	% Mn \ Trt	G_s‡‡	G_m¶	R_h§§	D_c††
2.06	1.94	2.71	2.72	2.80	2.77
2.89	0.94	2.67	2.74	2.79	2.79

Al-Zn-Cu (26)

% Zn	% Cu \ Trt	G_s‡‡	G_m¶	R_h§§
3.50	2.31	2.80	2.81	2.83
4.76	0.87	2.77	2.79	2.80
4.71	2.67	2.82	2.83	2.85
4.64	3.92	2.84	2.84	2.87
7.38	1.76	2.85	2.86	2.88
9.91	0.94	2.86	2.88	2.90
9.96	2.75	2.92	2.94	2.96
13.99	1.64	2.99	3.00	3.02
14.74	2.50	3.02	3.03	3.06
18.45	0.80	3.08	3.09	3.11
18.95	1.66	3.08	3.10	3.12
23.48	2.67	3.22	3.21	3.26

Wrought Commercial Alloys

% composition	Name	d_4^{20}	Lit.
Cu, 3.5–4.5; Mn, 0.5–0.8; Mg, 0.5...	‖‖	2.75–2.83	(9)
Cu, 4; Ni, 2; Mg, 1.5¶¶...........	Y	2.80	(23)
Zn, 20; Cu, 3¶¶...................	A	3.10	(23)
Zn, 20; Cu, 2.5; Mg, 0.5; Mn, 0.5...	E	3.10	(23)
Cu, 3.25; Mg, 0.70; Mn, Tr.***.....		2.80	(21)

* For specific gravity of pure aluminium, v. p. 456.
† % Al by difference.
‡ Dimensions are diameters unless otherwise indicated.
§ Thickness.
‖ Corrected to *in vacuo*.
¶ G, 1 in. diam.
** Contains Fe, $\ngtr 1$; Si, $\ngtr 1$.
†† To 13/16 in. diam.
‡‡ G to shape (0.56 in. diam.).
§§ To 7/8 in. diam.
‖‖ Duralumin.
¶¶ Contains Fe, 0.2; Si, 0.2.
*** Contains Fe, 0.28; Si, 0.28.

TABLE 9.—MOLD SHRINKAGE (26)

% composition*	$-100 \frac{\Delta l}{l_0}$†
Cu, 12, L 8................................	1.25
Cu, 14; Mn, 1.............................	1.21
Cu, 7; Zn, 1; Sn, 1, L 11....................	1.19
Cu, 4; Ni, 2; Mg, 1.5, "Y" alloy (23)........	1.29
Zn, 13.5; Cu, 2.5, L 5......................	1.27

* Nominal composition, all contain Fe, 0.20 and Si, 0.20 (nominal).
† Bars cast in sand between faces of steel template and measured when cold.

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PROPERTIES OF ALLOYS OF ALUMINIUM WITH

FE, MG, MN, NI, NI-CU, SI, AND SI-CU

L. AITCHISON

MECHANICAL PROPERTIES

Wt. %	d_4^{20}	BHN	UTS	$10^{-2} E$	El
		Al-Fe (R, A) (8, 13)			
Fe 1	2.73	29	10.7	66	34
2	2.76	33	11.8	66	33
4	2.80	37	12.6	66	29
7	2.85	38	12.6	68	18
11	2.93	44	12.6	68	8
		Al-Mg (R, A) (1–3, 13, 14)			
Mg 0.5	2.69	30	10.2	66	36
1.0	2.69	33	12.6	66	35
2.0	2.68	39	15.8	65	33
4.0	2.65	54	18.9	64.5	22
6.0	2.63	69	28.4	63	20
		Al-Mg (G_s) (1–3, 13, 14)			
Mg 2	2.68	34	12.6	64.5	3
4	2.65	35	12.6	63	3
5	2.63	36	14	63	3
10	2.57	40	16	61.5	3

MECHANICAL PROPERTIES.—(*Continued*)

Wt. %	d_4^{20}	BHN	UTS	$10^{-2} E$	El
		Al-Mg (G_m) (1–3, 13, 14)			
Mg 2	2.68	40	19	64.5	2
4	2.65	60	19.5	63	2
5	2.63	65	19.5	63	2
10	2.57	80	22	61.5	2
		Al-Mn (R, A) (3, 13)			
Mn 0.5	2.71	30	11	66	33
1.0	2.73	33	12.5	66	30
1.5	2.75	35	12.5	66	28
2.5	2.78	39	13.5	66	22
5.0	2.82	46	14	66	18
8.0	2.86	50	15	66	17

MECHANICAL PROPERTIES.—(*Continued*)

% Ni	d_4^{20}	*BHN*	*UTS*	10^{-2} *E*	*El*	*RA*
Al-Ni (R, A) (3, 8, 11, 13)						
1	2.72	34	11.8	66	32	52
2	2.75	38	12.5	66	30	50
3	2.77	44	14	66	27	45
4.5	2.80	44	15	66	25	42
6	2.82	45	15	66	22	35
8	2.85	47	15	66	16	24
10	2.91	53	16.5	66	8	12

% Ni	d_4^{20}	*BHN*	*UTS*	*YP*	*El*	*RA*
Al-Ni* (G_m) (3, 8, 11, 13)						
1	2.71	34	10	4	9	21
5	2.80	45	15	6.3	11	36
8	2.86					
Al-Ni-Cu* (G_m) 1% Cu (11)						
1	2.73	37	13.4	4.7	19	29
5	2.83	45	17	7	6	8
Al-Ni-Cu* (R, A) 2% Cu (11)						
1	2.77	53	16.5	6.3	30	57
5	2.82	60	19	7	25	36

% Si	d_4^{20}	*BHN*	*UTS*	*PL*	10^{-2} *E*	*El*
Al-Si (G_s) (1–3, 5–7, 9, 10, 12)						
5	2.65	40	12.6	2.4	63	5.5
8	2.63	44	12.6	2.4	63	5.5
13	2.60	50	14.5	3.2	60	2
Al-Si (G_sM) (1–3, 5–7, 9, 10, 12)						
8	2.63	47	15.7	3	63	9
10	2.62	50	15.9	4.7	61	8
13	2.60	50	18.9	4.7	60	8

Al-Si (R, A) (1–3, 5–7, 9, 10, 12)

% Si	*BHN*	*UTS*	*El*
1	28	9.5	45
1.5	30	9.9	43
2	30	10.3	41
5	35	11.8	35
10	40	12.6	27
15	47	14.2	17

* 10^{-2} *E* = 66.

THERMAL PROPERTIES

Annealing Temperatures

250°C for Al-Mg (R, A).
275°C for Al-Fe, Al-Mn, Al-Ni (R, A), Al-Ni-Cu (R, A).
300° for Al-Mg (G_s and G_m), Al-Ni (G_m), Al-Ni-Cu (G_m), Al-Si.

Mold Shrinkage

Al-Mg (1–3, 13, 14)

	Trt \ % Mg	2	4	5	8	10
$-100\frac{\Delta l}{l_0}$	G_s	18.2	17.6	16.5	14.7	14.5
	G_m	17.2	16.6	15.5	13.8	13.5

Al-Mn (3, 13)

	Trt \ % Mn	1.5
$-100\frac{\Delta l}{l_0}$	G_s	21.0
	G_m	19.3

Al-Ni (G_m) (3, 8, 11, 13)

% Ni	1	5	8
$-100\frac{\Delta l}{l_0}$	17.2	17.2	17.0

Al-Ni-Cu (G_m) 1% Cu (11)

% Ni	1	5
$-100\frac{\Delta l}{l_0}$	17.2	17.0

Al-Si (G_s) (1–3, 5–7, 9, 10, 12)

% Si	3	5	8	13
$-100\frac{\Delta l}{l_0}$	16.9	16.6	16.3	16.0

Al-Si (G_sM) (1–3, 5–7, 9, 10, 12)

% Si	8	10	13
$-100\frac{\Delta l}{l_0}$	16.3	16.0	16.0

Al-Si (G_m) (1–3, 5–7, 9, 10, 12)

% Si	3	8	10
$-100\frac{\Delta l}{l_0}$	15.2	14.4	13.3

Al-Si-Cu (G_s) 2% Cu (4)

% Si	3	6	9
$-100\frac{\Delta l}{l_0}$	17.1	15.8	16.0

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PROPERTIES OF MAGNESIUM AND OF ITS ALLOYS WITH MORE THAN 50% MAGNESIUM

ALBERT M. PORTEVIN

Mg

Treatment	*UTS*	*YP*	*El*	*RA*	Lit.
F	23.6				(2)
DA	18–22	8–13	$8–12_l$		(21, 22)
G_s	14.1 10.7	*v. also* under Mg-Al	8_s 5		(2) (18)
G_m	12.4		4		(18)
R/83°			10_l	13	(16)

UCS = 27.1 kg/mm² (3).
EL_C = 1.18 − 5.80 (metal W_{H_2} 600°/60)*(11).
E = 4260 kg/mm² (28).
G = 1700 kg/mm² (19).
K = 2800 kg/mm² (19).
ScH = 18 for G_s (8).
BHN† = 29.4_{BV} (25); 28.6_{CX} (27); $22–25_{C(V-Z)}$ (15).
Log BHN_1 − log BHN_2 = 0.0012 ($t_2 - t_1$) (14); *v. also* Fig. 1.

From experiments at B. P. of air at 10°, 15°, 50° and 70° C, $\frac{E_{0°\ abs.}}{E_{0°C}} = 1.57$ (17).

For specific gravity, *v.* p. 456; for compressibility, *v.* vol. III; for viscosity, *v.* vol. III; for surface tension, *v.* vol. III.

Mg-Ag

% Ag	3.4	9.8	36.0	41.5	Lit.
BHN_{BV}†	40.1	48.5	104.7	136.2	(25)

Mg-Al

Sand cast (8)

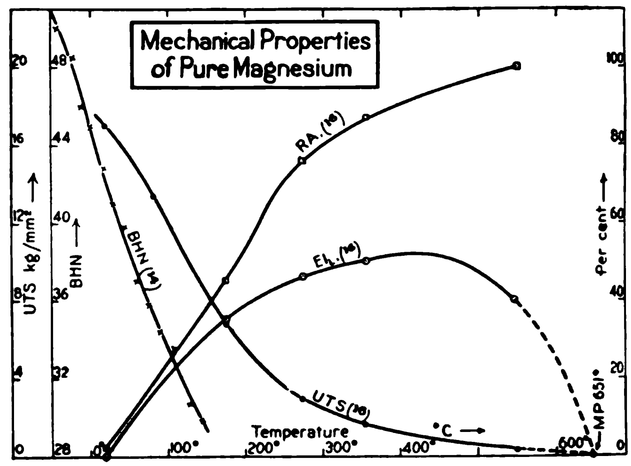
% Al	100 × d_4^{20}	Hardness BHN_{CZ}†	Hardness *ScH*	Tensile properties 10 × *UTS*	Tensile properties 10 × *PL*	Tensile properties 10 × El_a	10 × *UCS*	10 × *BMR*
0	174	60	28	100	14	54	175	225
2	174	45	19	169	35	101	250	301
4	175	50	22	184	44	84	289	336
5.8	176	53	22	197	56	74	293	360
6	176	53	24	197	56	74	293	360
8	177	60	28	178	63	40	299	344
10	179	66	32	161	77	20	314	324
12	180	71	34	148	91	10	315	304
15	182	75	38	117	112	5	319	311

Al, 8 (Dowmetal A): *UTS* = 21.8, *UCS* = 31.1; *BMR* = 432, *E* = 4260 kg/mm² (8).
Sand cast; annealed 2 hr at 800° (8).

% Al	Treatment	10 × *UTS*	10 × *YP*	10 × *El*	10 × *PL*	10 × *RA*	Lit.
2.5	DA	231	133	150_l	Al, 0–5, sp. vol. = 0.575–0.0026 Al (23)		(21, 22)
3	FA 450° G_m	231 85	105–148 82	95–150 10			(26) (26)
4.5	DA	248	150	173_l	Al, 6–11, *E* = 4400 kg/mm² (1)		(21, 22)
5	DA	254	142	180_l			(21, 22)
6.12	D RA 300° G_{hm} G_m G_s	295–309 290 143–154 181 100	 262–270 83–85 	 $75–80_l$ $45–50_l$ 50 70	 88–129 28 % Al 4	 46 (QA) *LCH* (16) 69.0–71.0	(1) (1) (1, 5) (18) (18)
8	G_m FA 400°/30.	235 200	133 150	5–10 20	8 15	83.0–84.8 91.0–91.8	(26) (26)
11	DA	280	220	80_l			(20)
11.18	G_{hm}	134–146	130–135	10_s	31	3.4	(1, 5)
15	G_m	119	119	0			(26)
28	G_m	55	55	0	Al, 7; BHN_{CZ} = 50		(21, 22, 26)

Mg-Al-Cu

% Al	% Cu	Treatment	*UTS*	*YP*	El_l	Lit.	Treatment	*UTS*	Lit.
10.7	1	DA	30.5	20	8.5	(14)	D_c 20 %	30	(21, 22)
8	9		28	20	5	(15)			



Mg-Al-Cu-Cd, Etc., Dowmetals D, R and T (G_s) (8)

% composition Al	Cu	Cd	Zn	Mn	Name	100 × d_4^{20}	BHN_{CZ}†	*ScH*	10 × *UTS*	10 × *PL*	10 × El_a	10 × *UCS*
8.3	2.0	1.0	0.5	0.2	D	184	58	29	155	98	20	299
8.0	1.0	1.0			R	181	54	23	165	67	45	302
2.0	3.8	2.0		0.2	T	184	45	24	145	98	37	239

Mg-Al-Ni

% Al	% Ni	Trt	10 × *UTS*	10 × *YP*	10 × *El*	Lit.
8.6	0.7	DA	295	165	130_l	(20)

Mg-Cd

% Cd	Trt	10 × *UTS*	10 × *YP*	10 × *PL*	10 × *El*	10 × *RA*	Lit.	% Cd	*BHN*† (27)
1.1	F	222	177		50_s	69	(1)	16.1	31.9_{CX}
	R	180–183	176	91	$7.5–10_s$		(1)	19.6	34.9_{CX}
	D	152–181	176				(1)	23.7‡	46_{CX}‡ 13.5_{CW}
	G_{hm}	70	44	19	35_s	31	(1)		
4	DA	206	118		75_l		(21, 22)	34.1	42.6_{CX}
5.5	DA	206	124		113_l		(21, 22)	45.1	51.0_{CX}
								53.7	64.9_{CX}

Cd, 0–6: sp. vol. = 0.575–0.0047 Cd (23).
Cd, 1: *E* = 4400 kg/mm² (1).

Mg-Mn

Mn, 0–4; specific volume = 0.575–0.0043 Mn (23).

Mg, 98.8; Si, 1.2 (DA)

UTS = 29 kg/mm²; *YP* = 22.2 kg/mm²; El_l = 5% (20).

Mg-Sn (QA)

Sn, 4: *LCH* = 57.0–60.0; Sn, 8: *LCH* = 68.0–70.0; Sn, 15: *LCH* = 79.0–79.5 (16).

Mg-Cu

% Cu	Treatment	$100 \times d_4^{20}$	*BHN*	*ScH*	$10 \times UTS$	$10 \times YP$	$10 \times PL$	$10 \times El$	$100 \times RA$	$10 \times UCS$	Lit.
3.02	RA 300°				171–189	162		10_s			(1)
4	G_s	179	43	26	109		35	15_s		211	(8)
	QA	*LCH* = 62.0–64.5			Cu 4 (G_s) is Dowmetal S						(16)
4.5	DA				209	146		45_l			(21, 22)
8	QA	*LCH* = 77.0–80.3								Cu, 3–14, *E* = 4400 kg/mm² (1)	(16)
9	DA	Cu 0–13, sp. vol. = 0.575–0.0052 Cu (23)			234	200		30_l			(21, 22)
12.7	DA				246	219		20_l			(21, 22)
13.64	G_{hm}				120	116	31	7.5_s	36		(21, 22)

Mg-Zn

% Zn	Trt	*UTS*	*YP*	$10 \times El$	Lit.
2.5	DA	23.0	11	170_l	(21, 22)
3.8	DA	23.7	12	145_l	(21, 22)
5	G_s	18		74_s	(8)
8	G_m	17		30	(18)
	G_s	14.3		40	(18)

% Zn	Trt	*BHN*†	*ScH*	Lit.
5	DA	45cz		(21. 22)
	D_d	67cy		(8)
	‖	47cy		(8)
	G_s	41cz		(8)
			23	(8)

% Zn	*LCH* for (QA) (16)
4	62.0–65.8
8	77.0–78.7
15	103–104

Zn, 5–15, is "electron;" Zn, 0–5: sp. vol. = 0.575–0.0043 Zn (23); Zn, 4: *E* = 4400 kg/mm² (1).

Mg-Zn-Al (21, 22) ‖ Mg-Zn, 4.3; Al, 1.6; Cu, 0.74 (D) "Electron" Metal (1)

Composition	Treatment	*UTS*	El_l	Zn	Al	Treatment	*BHNcz*†	*UTS*	*YP*	*PL*	El_s	*RA*
Zn, 3; Al, 0.5	D_o 30 %	32	3.5	3	2	DA	45	25.3	23	7	11.0	13.4
	D_o 10 %	27	8	1.8	5	DA	50	to		to	to	to
	DA	23	17	5	2	DA	50	27.7		10	12.5	16.3

Mg-Zn-Cu, "Electron" Metal

% composition Zn	% composition Cu	$100 \times d_4^{20}$	BHN_{AU}†	Tension‖ $10 \times UTS$	Tension‖ $10 \times YP$	Tension‖ El_s	Tension‖ *RA*	Compression¶ $10 \times UCS$	Compression¶ $10 \times YP$	*IS* Charpy kg-m/cm² (13)	Lit.
4.24	0.42	179	51–48**	283	119	19		352	95		(4)
4.62	.20	178	51–50**	253	189	19		363	47		(4)
4.37	.62	179	63–59**	289	189	13		377	132		(4)
"Electron"		181–183		232	13	15	16			0–1.0	(6,7)

* Heated in hydrogen.

† Subscripts to Brinell hardness Nos.:

Subscripts	Ball diam., mm	Subscripts	Load, kg	Subscripts	Load, kg
A	1	U	10	X	200
B	5.564	V	50	Y	250
C	10	W	116	Z	500

‡ Tested at 300°C (8).

§ G, Q_w.

‖ Round bars, 7–6 mm diam.

¶ Cylinders, 7.85 mm × 7.85 mm diam.

** Exterior and transverse section, respectively.

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(For a key to the periodicals see end of volume)

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ZINC AND ITS ALLOYS CONTAINING MORE THAN 50% ZN

C. Benedicks

Table 1.—Mechanical Properties

Zn

Trt	R			Tested in liquid air					G	Single crystal
					A 100°	A 200°	A 200°	A 300°		
UTS	12–26	17	15–30	27	15*	14†	6–16*	5*	3	2.2–2.5
Lit.	(40)	(41)	(38)	(36, 37)					(48)	(35)

*A 30 m. †A 5 m.

YP = 9 ± 3 kg/mm² (40).
Extrusion Pressure = 75 kg/mm² (29).
PL and *EL*: None defined (6, 11, 13); *cf.* however (16).
EL = 5–30 % on 150 mm; *RA* = 5–60 % (6, 40).
For *UTS* and *El* vs. t,°C; *v.* Fig. 1; *v. also* (38, 45).

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

	A at: t,°C		70	100	150	200	250	300	350	380
(45)	*UTS*	17.6	15.7	15.7	15.4	17.0	12.4	10.2	5.5	5.2
	El_a	30	41	42	38	13	11	9	2	3

Obs. *BHN* *H*	Red. *BHN* H_r	Ball diam. mm	Load, kg	Lit.
46	46	10	500	(12)
31*	35	10	50–100	(29)
40	40	10?	500	(31)
61†	52	5	500	(7)

* Rate of indentation = 0.25 mm/min. † Rolled.

H_r = *BHN* reduced to 10 mm, 500 kg by formula: $H_r = H\frac{x + P_0}{x + P}\sqrt[5]{\frac{\rho}{\rho_0}}$ (8), where ρ = radius of ball, P = load (kg), $x = 3700$ for $140 < P < 500$. Reduction to 10 mm, 3000 kg not performed as being uncertain. Concerning reduction, *v. also* (3).

Trt	G	Wk_c	A 80°	A 100°	A 125°	A 250°
*BHN**	38	64	64	51	43	43

Temp., °C	−50	−25	0	25	50	75	100	125
BHN†	88	78	69	61	54	47	41	36

* 1 mm ball; 5 kg load (39). † Faired values (24).

LCH = 62 ± 2 (31).

ScH = 10 (31); 11 (42); 10.8 (9); *v. also* Fig. 2.

For some typical hysteresis diagrams, *v.* Fig. 3.

For: specific gravity, *v. p.* 456; compressibility, *v.* vol. III; viscosity, *v.* vol. III; surface tension, *v.* vol. III.

Zn-Al; *v. also* (20, 21, 25, 26, 43)

Zn, 94; Al, 6 (A, t,°C)

t,°C	*UTS*	El_a
	23.2	66
70	27.5	60
100	22.3	54
150	22.2	49
200	25.0	24
250	28.3	21
300	23.8	43
350	22.7	43
380	22.3	42
(45)		

Trt / % Al	G_s (44) *UTS*	G_s *YP*	G_s El_a	G_m (44) *UTS*	G_m *YP*	G_m El_a
10	24.3	16.7	10.3	22.3	17.8	1.9
20	29.1	26.6	6.7	29.3	22.5	1.5
25	29.0	12.7	10.1	31.7	21.3	2.2
30	27.9	16.9	4.3	28.3	13.5	2.7
35	26.5	11.8	3.5	26.3	16.0	0.6
40	28.3	16.6	2.6	26.7	9.4	1.6
45	28.3	15.0	2.7	24.4	10.7	1.1
50	29.2	20.3	4.1	34.0	8.0	1.1

Al, 0–50: For *IS* of (G_s) or (G_m), *v.* Fig. 5. For *BHN* of (Q) or (A), *v.* Fig. 4; *v. also* Figs. 6 and 7.

LCH of Zn-Al, Q, or A 360°/2–3 h (30).

Trt / % Al	0.5	1	2	4
Q	61–64	82–85	86–91	74–80
A 360°	64–66	78–83	88–90	74–76

Zn-Al-Cu; *v. also* (20, 21, 25, 26, 43)

% Al / %Cu	Hot rolled (45) 1 *UTS*	1 El_a	1 *BHN*	3 *UTS*	3 El_a	3 *BHN*	9 *UTS*	9 *BHN*	Chill cast (45) 1 *UTS*	3 *UTS*	9 *UTS*
0	30.7	39	66	31.5	31	83	47.3	99	8.7	11.5	20.7
2	33.2	37	103						18.9		
4	34.1	28	104	33.0	51	115	56.0	129	22.0	24.7	28.0
6	38.2	50		36.5	57	107	45.0	134	22.3	28.4	26.6
8	33.2	38	110	35.2	50	123			27.8	28.3	
15	37.3	47	103	34.0	44	129	43.4	146	30.2	30.8	34.1

Cold rolled % Al	% Cu	*UTS*	El_a	Zn, 97; Al, 2; Cu, 1 (annealed at t°C) t,°C	*UTS*	El_a	t,°C	*UTS*	El_a
2	1	30.8	39		29.0	45	250	28.0	6
4	1	35.7	32	70	27.5	40	300	25.3	
4	3	31.3	17	100	29.2	35	350	27.6	8
6	1	35.3	4	150	27.3	39	380	22.8	5
(45)				200	29.3	15	(45)		

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

For *UTS*, YP_C, *BHN* of Al, 0–11; Cu, 0–10; *v.* Figs. 6 and 7.

Zn-Cd

Values of *LCH* (30); *v. also* Figs. 5, 6, p. 549, 550; (17) and (49)

Trt / % Cd	0.25	0.5	1	2	4	8
Q	63–65	74–75	89–91	94–95	85–89	78–79
A 260°/2–3 h	65–73	79–85	94–100	98–103	96–98	85–89

For *USS*, *v.* Fig. 8, p. 550.

Zn-Cu; *v. also* (20, 21, 25, 26, 43)

% Cu	*UTS*	YP_C	*BHN*
0	3.4	0.0	40
1.75	4.3	22.5	60
4.1	13.9	22.5	75
6.7	18.2	23.7	82
8	21.0	23.2	85
10.5	22.7	30.0	100
(48)			

% Cu*	*UTS*	El_a
0	9.1	0
1	24.8	54
3	34.0	13

Zn, 97; Cu, 3 (A, t,°C)

t,°C	*UTS*	El_a
	28.8	36
70	28.6	34
100	27.4	35
150	27.2	38
200	29.2	35
250	21.5	
300	21.7	37
350	22.5	40
380	21.7	33
(45)		

Trt / % Cu	G *BHN*	A *BHN*
0	35	35
3.5	64	56
5.0	74	61
8.7	57	65
14.3	64	73
19.4	102	102
25.0	189	143
44.7	188	174
49.5	93	93
(26)		

* Cold rolled alloys (48)

Zn, 51.97; Cu, 48.03 (15)

Temp., °C	16	300	450	500	600	700	760	820
*IHN**	166	174	169	132	62	38	26	22

* For method, *v.* (14).

LUDWIK CONE HARDNESS OF ZN-MG, ZN-SB, AND ZN-SN (30)

Trt / Wt.%	Q	A 350°/2–3h	Trt / Wt.%	Q	A t°/2–3h	t,°C
Mg 0.25	87–90	76–79	Sb 1	47–50	51–53	390
0.5	92–99	87–97	2	51–52.5	54–55	
1	101–103	102–103	Sn 4	42–43	40–42	150
2	111–116	128–129	8	40–41	38–39	

TABLE 2.—ELASTIC PROPERTIES OF ZN

E	10 480	10 300	9 600	8 000–13 000	8 090			
G	3 800	3 880				3 100	1 600	2 990
Lit.	(28)	(52)	(40)	(18)	(41)	(50)	(47)	(23)

Temp., °C	18	21	48	52	63	67	82	97	
G	3110	3100	2980	2890	2810	2790	2620	2440	(50)*

$\frac{1}{E}\frac{dE}{dt}$ = 0.0035 per °C (53) (very uncertain extrapolation).†

* *v. also* (23, 27, 51).

† *v. also* (34).

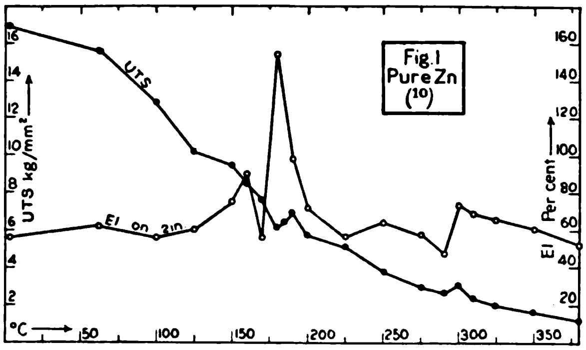
ELASTIC CONSTANTS OF A SINGLE CRYSTAL (19)

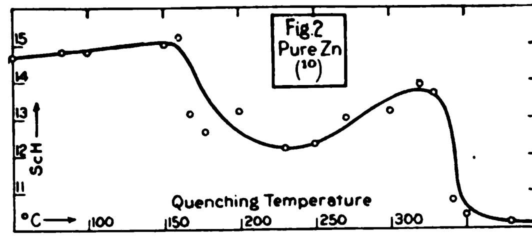
φ = angle between axis of tension and hexagonal axis.

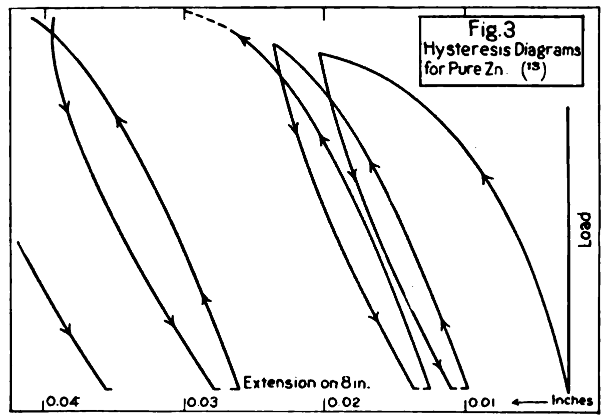
φ	3.6	4.7	22	23	30	37	48	56	81	81	88
$10^{-1}E$	359	356		472	539	675	878	1162	1230	1267	1178
$10^{-1}G$	374	377	350	328	333	324	289	315	464	473	479

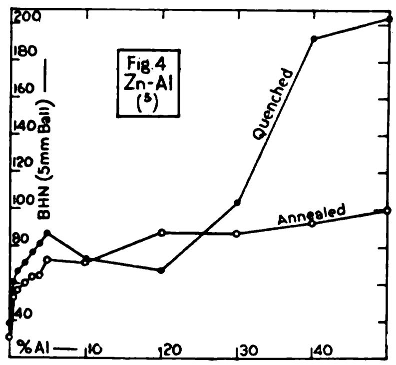
K = bulk modulus = 10 100 kg/mm² (52).

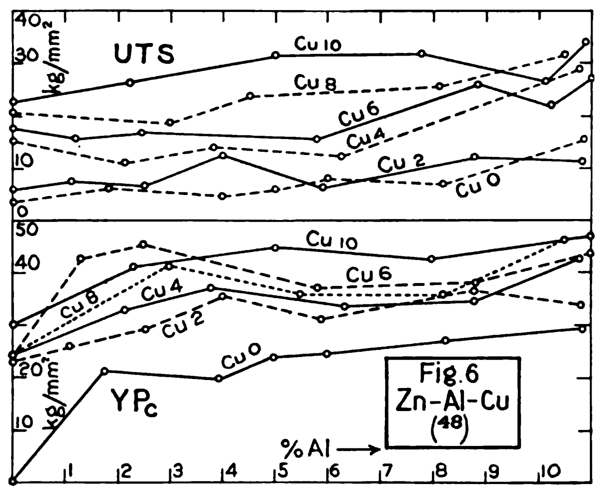
λ = 0.3 (52); λ = 0.33 (calc. from G and E) (47).

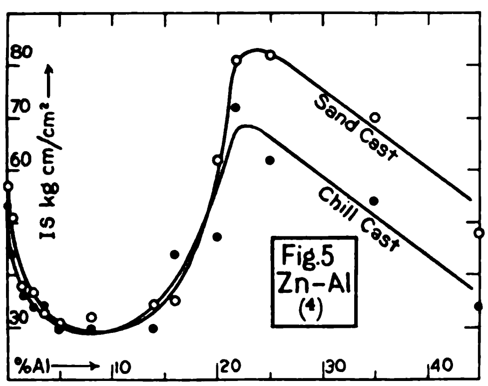


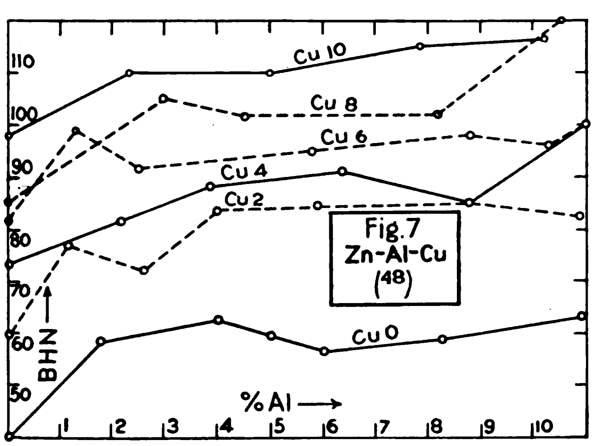












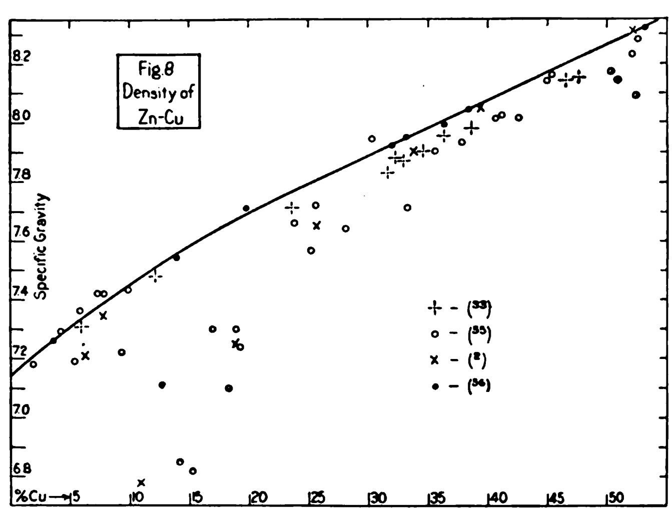


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TABLE 3.—COMPRESSIBILITY OF ZN ALLOYS* [32]

Wt. %	Temp., °C	Range, atm.	$10^6 \chi$ per atm.
Al 5	19.0	1–1050	1.9
25	15.4	1–1050	2.3
50	18.0	1–1050	1.8
Cd 10	21.5	1–1050	1.7
40	22.5	1–1050	2.8
Cu 10	6.0	1–1050	1.8
30	25.2	1–1050	1.5
50	20.5	1–1050	1.9
Pb 20	9	1–2100	1.6
	104	1–2100	3.3

* For compressibility of pure Zn, *v.* vol. III.

TABLE 4.—SPECIFIC GRAVITY OF ZN ALLOYS

For specific gravity of pure Zn, *v.* p. 456

Zn-Al [44]

Chill cast % Al	Chill cast d_4^{20}	Sand cast % Al	Sand cast d_4^{20}
9.59	6.120	9.69	6.182
19.40	5.380	20.03	5.458
25.37	5.008	24.98	5.043
30.78	4.768	30.58	4.707
34.65	4.383	35.20	4.487
40.80	4.123	40.37	4.290
44.85	4.103	45.02	3.992
50.30	3.920	50.38	3.906

Zn-Cu

v. Fig. 8. The low values obtained by many investigators in the range 5–30% Cu are due to shrinking cracks and porosity. Values of [55] are checked by X-ray analysis.

Zn, 65; Sb, 35* [46]

t,°C	20	600	700	800	900
d	6.56	6.20	6.14	6.07	6.01

* M. P. = 510°C.

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(For a key to the periodicals see end of volume)

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(30) Ludwik, *93*, **94**: 161; 16. (31) Ludwik, *77*, **40**: 1547; 20. (32) Lussana, *59*, **19**: 182; 10. (33) Maey, *7*, **38**: 289; 01. (34) Mallock, *5*, **95**: 429; 19. (35) Mark, Polanyi and Schmid, *96*, **12**: 58; 23. (36) Martens, *Mitt. aus den kgl. techn. Versuchsanstalten zu Berlin Ergänzungsheft*, **4**: 1; 89. (37) Masing and Polanyi, *96*, **28**: 169; 24. (38) Mathewson, Trewin and Finkeldey, *80*, **64**: 305; 21. (39) Matveev, *74*, **8**: 708; 11.

(40) Meyer, *424*, **53**: 538; 05. (41) Moore, *86*, No. **52**; 11. (42) O'Neill, *58*, **111**: 430; 23. (43) Portevin, *74*, **8**: 720; 11. (44) Rosenhain and Archbutt, *403*, **2**: 319; 12. (45) Rosenhain, Haughton and Bingham, *47*, **23**: 261; 20. (46) Sauerwald, *95*, **14**: 457; 22. (47) Schaefer, *8*, **5**: 220; 01. (48) Schulz and Waehlert, *187*, **16**: 195; 19. (49) Stone, *40*, **12**: 11; 18. *80*, **60**: 303; 19.

(50) Sutherland, *3*, **32**: 31; 91. (51) Tomlinson, *5*, **40**: 343; 86. (52) Voigt, *8*, **45**: 674; 93. (53) Wahlberg, *220*, **56**: 79; 01. (54) Wassmuth, *75*, **115**: 223; 06. (55) Weber, *8*, **62**: 666; 20. (56) Westgren and Phragmén, *3*, **50**: 311; 25.

CADMIUM AND ITS ALLOYS WITH AG, AS, AU, BI, CU, HG, MG, PB, SN, TL, AND ZN

C. H. M. JENKINS

Cd (*v. also* Fig. 1)

Treatment	*UTS*	*El*	*RA*	Lit.
G_m, 1 in. diam.	8.5	52	80	[7.3]
R_c, V 12 mo.	7	95	>90	[7.3]
R_c, V 12 mo, 300°/1 d.	6.1	64	85	[7.3]

$$\left.\begin{array}{l} 10^{-3}E = 7.07_0 \\ 10^{-3}G = 2.45_0 \end{array}\right\} [17].$$

$E_{0°C}/E_{0°abs.} = 2.50$ (by damping of wires) [13].

$$BHN = \left\{\begin{array}{l} \text{21–24 (as cast)} \\ \text{21 (worked, aged 1 mo)} \end{array}\right\} \text{10 mm ball, 500 kg.}$$

Changes in hardness occur at atmospheric temperatures. Present values of *BHN* of worked material are unsatisfactory [2, 6].

$\log BHN_1 - \log BHN_2 = 0.00295\ (t_2 - t_1)$; between −45°C and +142°C (10 mm ball, 500 kg) [7].

For effect of temperature on properties, *v.* Fig. 1.

For: density, *v.* p. 456; compressibility *v.* vol. III; viscosity, *v.* vol. III; surface tension *v.* vol. III.

Cd-Ag

Compound Cd-Ag: *BHN* = 74 (10 mm ball, 200 kg) [12].

Cd-As

For density *v.* Fig. 7.

Cd-Au

For hardness *v.* Fig. 2.

Cd-Bi

For hardness *v.* Fig. 3.

Cd-Cu

Cast material [7.1]

% Cu	*UTS*	*El*	*RA*
Nil	8.75	65	80
Nil	8.35	38	58
0.52	11.4	48	76
0.54	12.2	44	66
1.00	13.7	19	51
1.03	13.25	42	76
1.95	14.6	21	3
2.00	15.2	18	13
2.86	15.45	3	2
2.90	14.9	4	3
4.83	15.5	0	0

Rolled material, aged 3 mo at room temperature [8]

% Cu	*UTS*	*El*	*RA*
Nil	8.8	58	>90
Nil	9.0	59	>90
0.54	10.4	50	>90
0.54	10.5	90	>90
1.00	11.8	44	>90
1.00	11.8	67	>90
2.00	13.7	50	68
2.00	13.1	38	64
2.86	13.85	21	10

Continued on p. 549

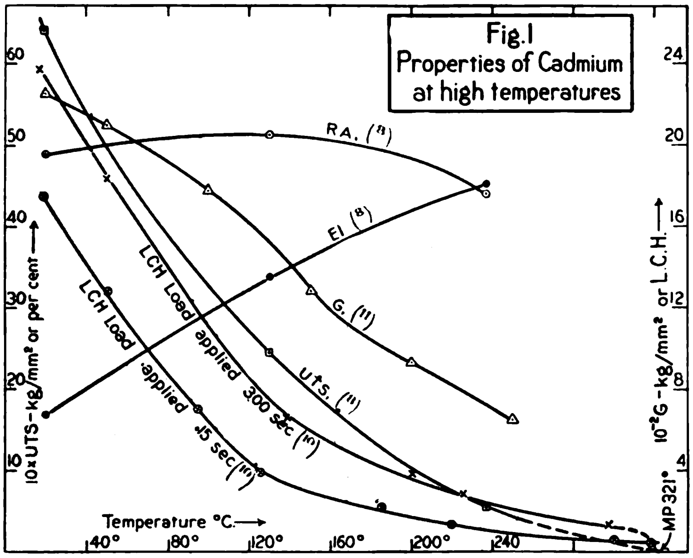


Fig. 1 Properties of Cadmium at high temperatures

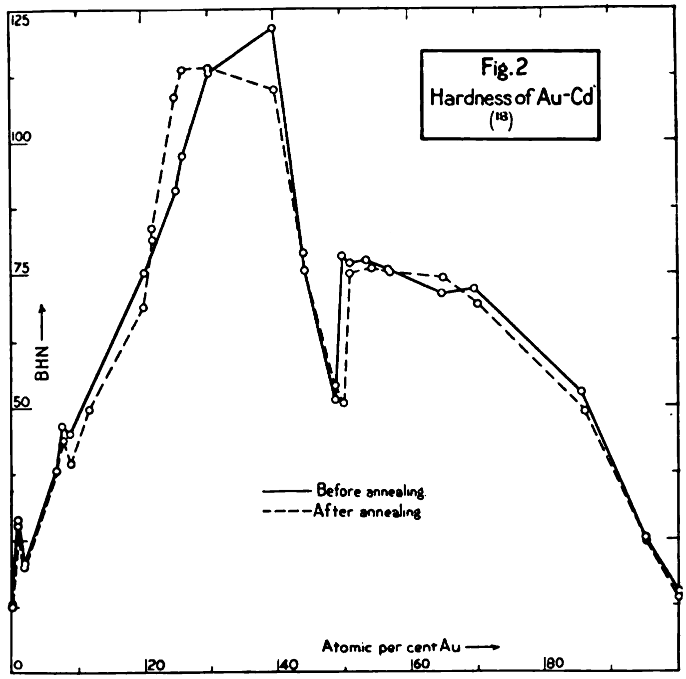


Fig. 2 Hardness of Au-Cd (18)

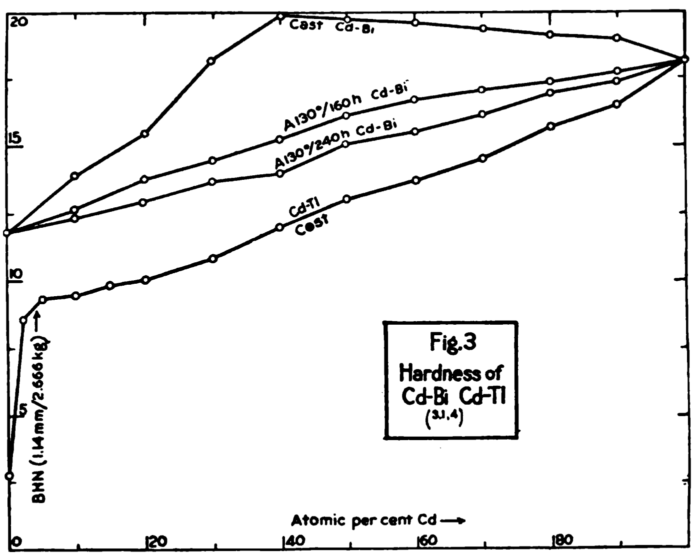


Fig. 3 Hardness of Cd-Bi Cd-Tl (3.1,4)

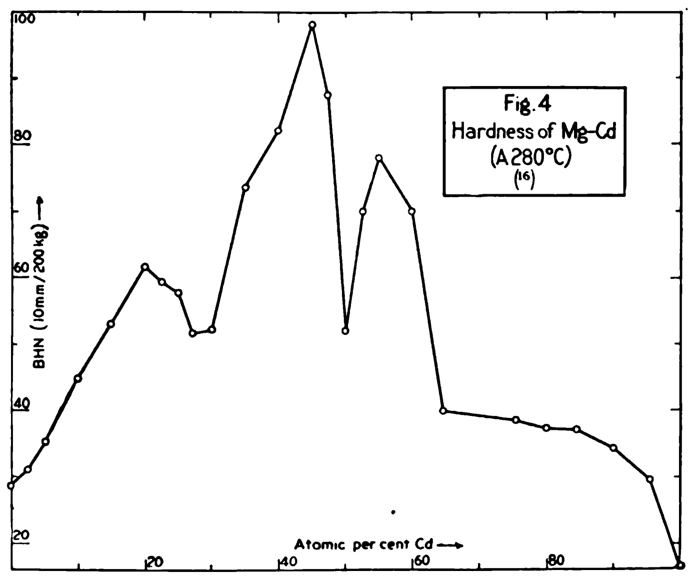


Fig. 4 Hardness of Mg-Cd (A 280°C) (16)

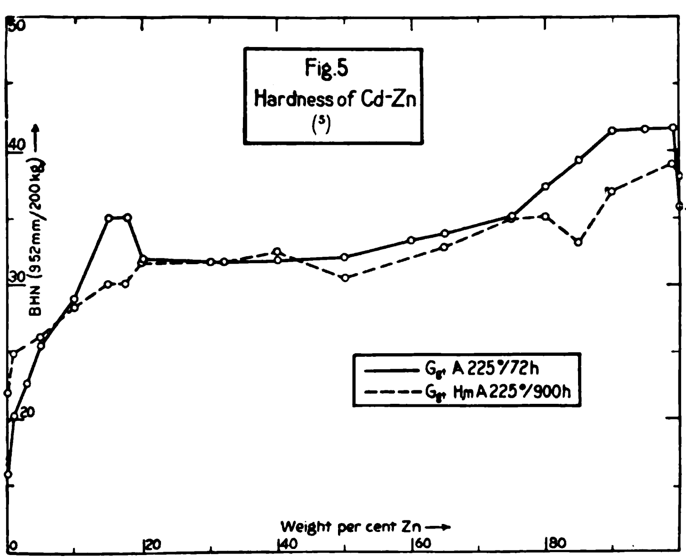


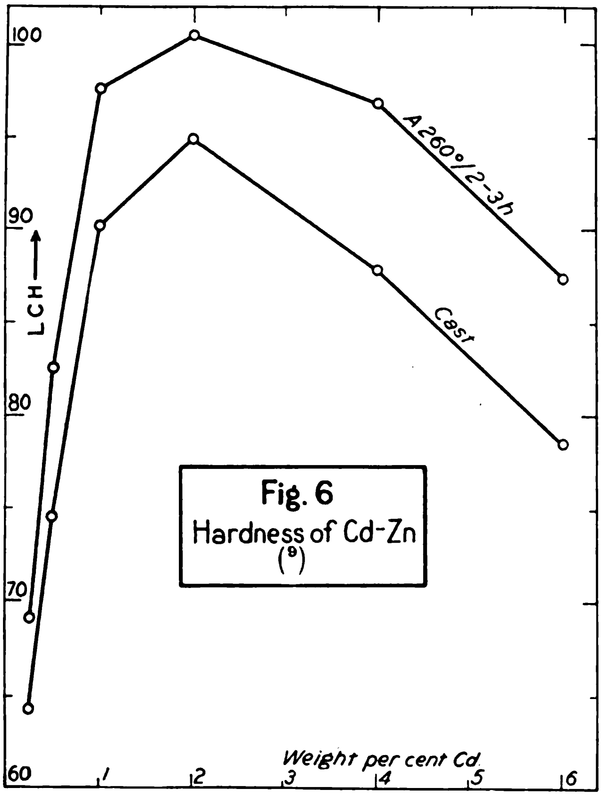
Fig. 5 Hardness of Cd-Zn (5)

Cd-Cu.—(*Continued*)

Annealed rolled material (annealed for 6 wk at 250°C. Reduction by rolling, 70%) (7.1)

% Cu	*UTS*	*El*	*RA*
Nil	6.9	54	86
Nil	6.85	61	87
0.52	11.35	50	74
0.52	11.2	58	80
1.03	12.75	38	68
1.03	12.9	50	70
1.95	14.2	36	42
1.95	13.7	37	42
2.90	14.5	24	15
2.90	14.0	25	25

Continued on p. 551



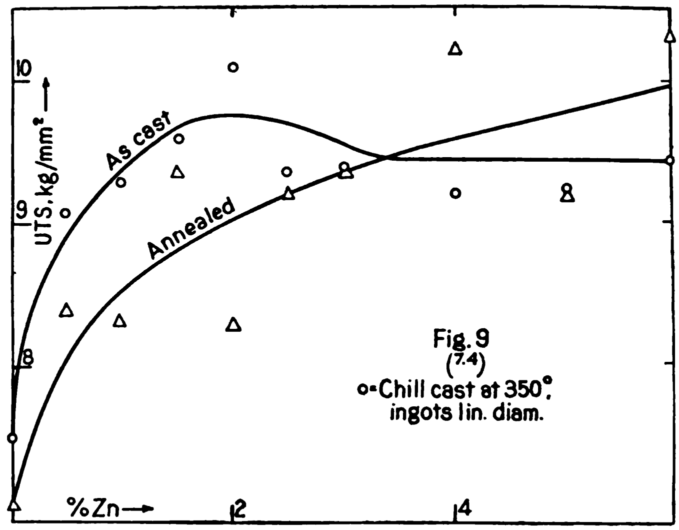
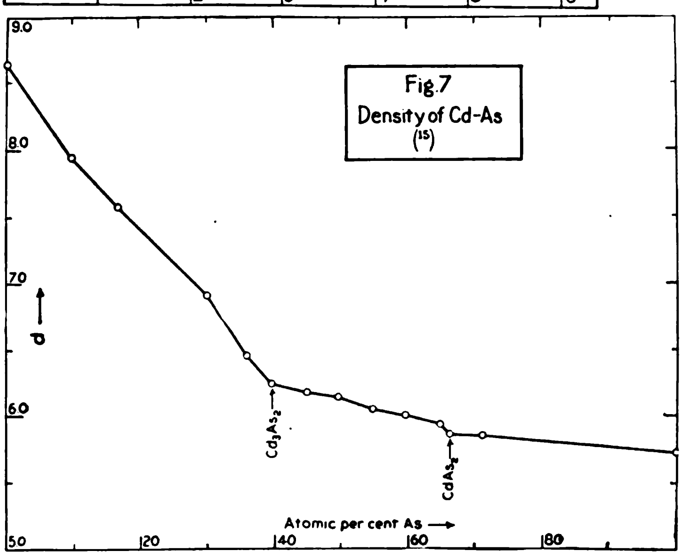
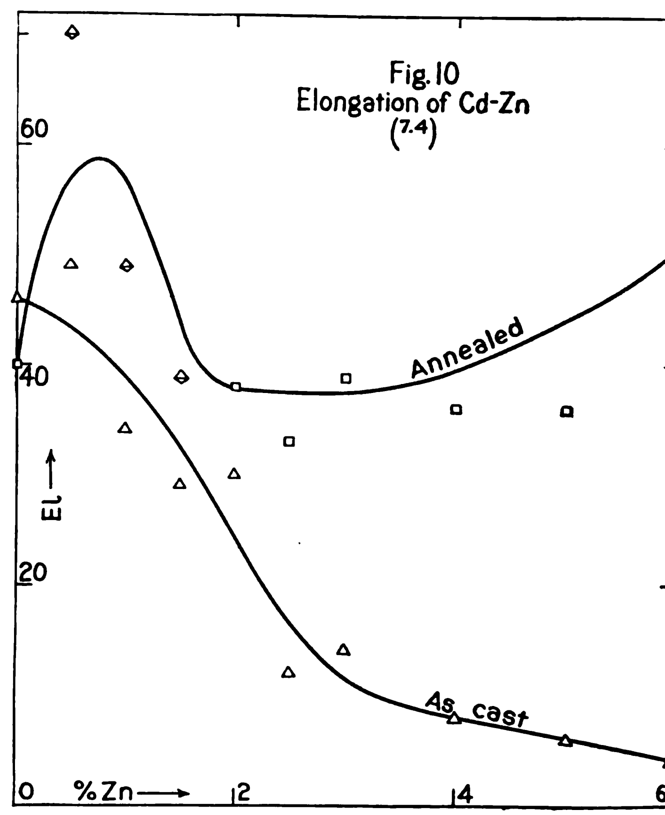
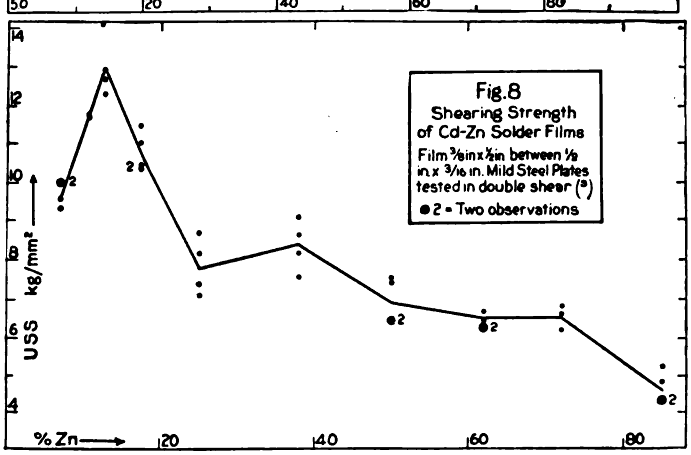
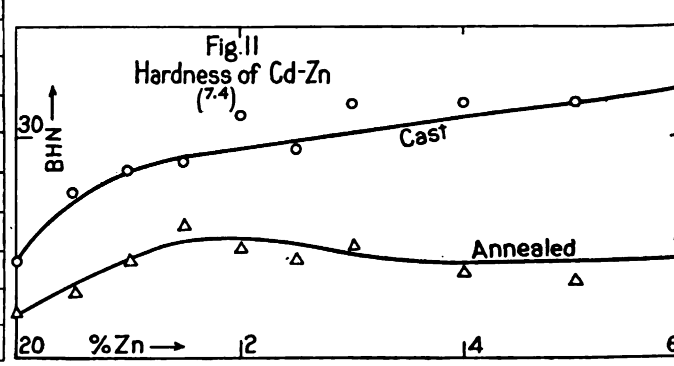


Fig. 9.—Tensile strength of Cd-Zn.









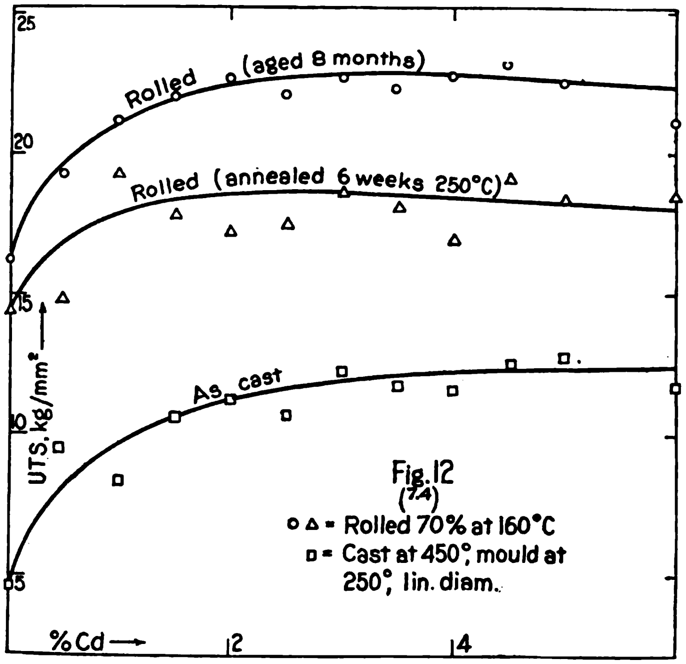
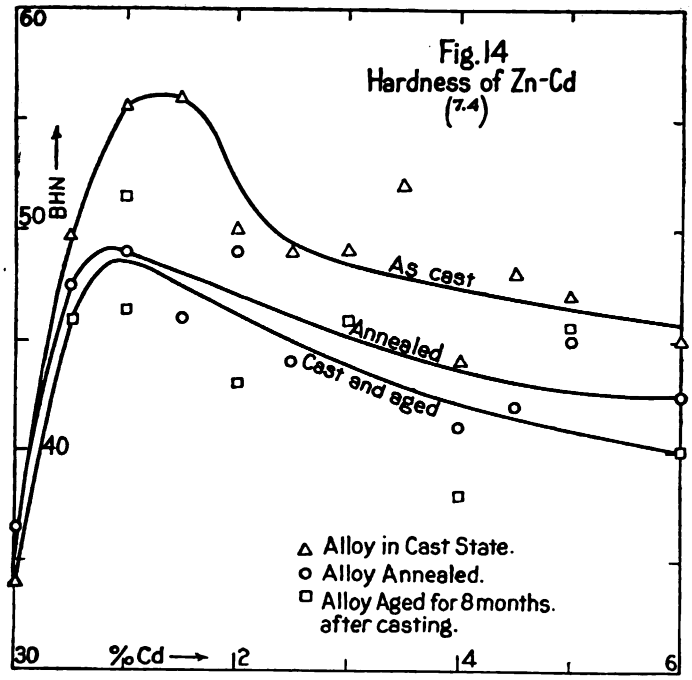
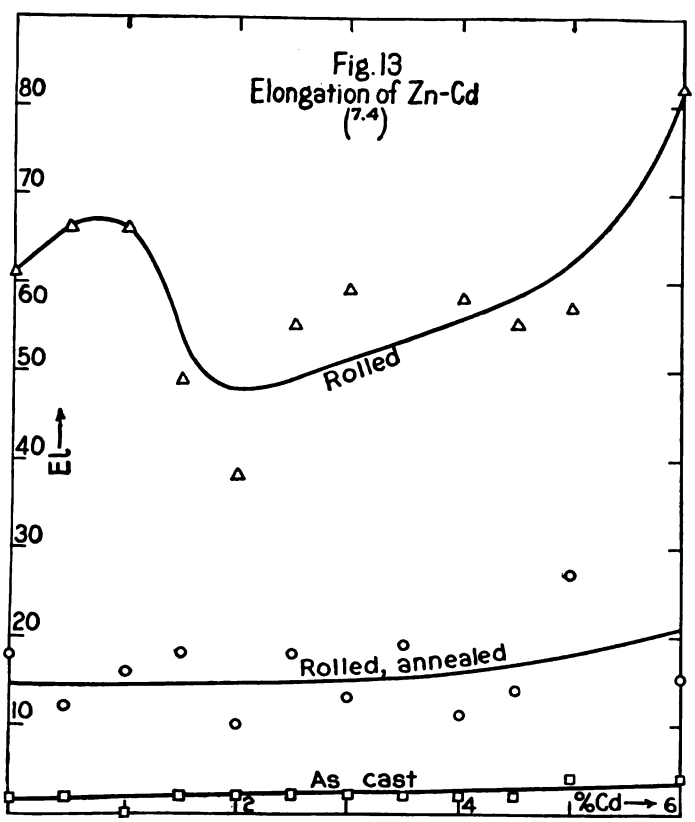


Fig. 12.—Tensile strength of Cd-Zn.





Cd-Cu.—(*Continued*)

% Cu	*BHN**		
	Max.	Min.	Mean
Cast material			
0	25	24	24.5
0.52	36	32	34
1.03	39	36	38
1.95	42	38	41
2.90	46	44	45
4.83	57	51	54
Material annealed for 6 wk at 250°C			
0	26	25	25.5
0.54	33	32	33
1.00	36	34	35
2.00	39	38	38.5
2.86	44	40	41.5
4.81	52	49	50

* 10 mm ball, 500 kg applied 3 min.

Cd-Hg

For density *v.* Fig. 10, p. 590.

Cd-Mg

Compound Cd-Mg: $BHN = 52$ (12) (10 mm ball, 200 kg); *v. also* Fig. 4.

Cd-Pb-Sn*

% Pb	% Cd	% Sn	d_4^{20}	*UTS*	*El*	Lit.
90	10	0	11.09	3.51	37.5	(1)
85	10	5	10.67			(1)
80	10	10	10.35	4.03	52.3	(1)
75	10	15	10.26	4.14	41.7	(1)

* Solders.

Cd-Tl

For hardness *v.* Fig. 3.

Cd-Zn (7.2); *v. also* Figs. 5, 6, 8–14.

% Cd	*UTS*	*El*	*RA*	Treatment
82.6	15.75	30	35	As cast*
82.6	11.6	68	90	A 250°/6 wt†
94.0	9.45	5	5	As cast*
94.0	11.4	60	90	A 250°/6 wt†

* Casting conditions: Poured at 270°C into cold cast iron mold 1 in. diam.
† Material reduced 70 % by cold rolling and annealed for 6 wk at 250°C.

LITERATURE

(For a key to the periodicals see end of the volume)

(1) Burgess and Woodward, *32*, **109**: 8; 19. (2) Cook, *47*, **29**: 119; 23. (3) Deeley, *47*, **34**: 193; 25. (3.1) di Capua, *22*, **32 II**: 343; 23. (4) di Capua and Arnone, *22*, **33 I**: 28; 24. (5) Glasunov and Matveev, *95*, **5**: 113; 14. (6) Greenwood, *83*, **17**: 681; 21. (7) Ito, *159*, **12**: 137; 23. (7.1) Jenkins, *47*, **34**: 103; 25. (7.2) Jenkins, *47*, **34**: 204; 25. (7.3) Jenkins, National Physical Laboratory, England, *O*. (7.4) Jenkins; *47*, **36**: Preprint, 26. (8) Ludwik, *98*, **59**; 657; 15. (9) Ludwik, *93*, **94**; 161; 16.
(10) Ludwik, *7*, **91**; 232; 16. (11) Koch and Dannecker, *8*, **47**; 197; 15. (12) Kurnakov and Zhemchushnui, *53*, **45**; 1004; 13. (13) Mallock, *5*, **95**; 429; 19. (15) Zhemchushnui, *95*, **4**; 228: 13. (16) Urasov, *169*, **14**; 675; 11. (17) Voigt, *8*, **49**: 717; 40. (18) Soldau, *53*, **46**: 1011; 14.

MECHANICAL PROPERTIES OF COPPER AND ITS ALLOYS WITH AG, AS, BI, CD, FE, MN, O, P, SB, AND SI

D. HANSON

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Density.	Densité.	Dichte.	Densità	554

TENSILE (COMPRESSIVE) AND ELASTIC PROPERTIES

Cu (*v. also* Figs. 1–4 and pp. 558–560)

Tensile properties of electrolytic Cu (RA 700°/30) (11)

Wt. % composition	*t*, °C	10^2*UTS*	El_a	*RA*
O_2, 0.015; Si, Tr	Room	2277	58	72.7
	250	1631	50.8	65.1
O_2, 0.016; Si, Tr	Room	2273	53.6	76.8
	250	1566	54	69.4

Compression of Cu cylinder 54.07 mm × 27.73 mm diam. (25)

P = Load, kg; A = cross-section area, mm²; A_0 = original cross section area, mm².

P/A_0	16.8	25.3	33.7	42.1	50.7	59.0	67.4	75.8	84.2
$-100\Delta l/l_0$	0.94	1.32	8.41	20.6	30.6	39.1	46.2	51.6	55.9
P/A	16.7	24.9	30.8	33.4	35.0	35.9	36.2	36.6	37.1

USS = *UTS*, same variations (24).
Electrolytic, annealed, $10^{-2}E = 123 - 131$ (8, 20, 23).
$E = E_0\,(1 + \alpha t)$, where $\alpha = -3.59 \times 10^{-4}$ (6, 26).
Pure, $10^{-2}\,G = 43.2$ (16).
$\lambda = 0.31 - 0.34$ (1, 8, 20).

Composition, hundredths %			*UTS*	*YP*	*El*	*RA*
As	O	Ag				
Cu-As (R_h to ⅛ in. diam., Q) (17)						
24			23.6	14.2	27*	*v. also* Figs. 1 and 4
53			25.2	13.4	29*	
75			24.9	12.6	21*	
94			24.4	12.6	25*	
137			25.7	12.6	28*	
180			24.4	16.1	20*	
Cu-As-Ag-O (R_cA *DR*/30 Q) (13)						
30	5.6	4.2	22.7		35_b	*v. also* Figs. 1, 3, 4,
42	6.3	9.4	22.9		35_b	
45	5.8	17.5	24.0		43_b	
42	4.8	29	24.1		43_b	

Composition, hundredths %			*UTS*	*YP*	*El*	*RA*
As	O	Ag				
Cu-As-O (4)						
26	12	0.7	24.4	14.8	40	79
94	15	0.8	25.4	13.6	54	70
194	20	0.5	26.0	9.8	62	80

Composition, hundredths %			*UTS*	*El*
As	O			
Cu-As-Bi-O (R_cA *DR*/30 Q) (13)				
42	5.5	Bi 5.1	23.8	42_b
40	6.8	7.3	22.8	40_b
39	8.4	9.7	23.2	33_b
47	7.3	12.4	23.3	35_b
Cu-As-Sb (A 800°/15) (14)				
36	6.5	Sb 20	23.5	48_b
Cu-As-Si-Fe (15)				
34	Fe 3.5	Si 2	24.4	43
36	6	20	24.6	50
35	7	15	25.1	40
39	13	22	25.7	37
38	13	36	25.5	41
35	24	80	28.8	37
37	5	0.0	25.5	46
69	43	0.0	27.0	48

* Gage length = 1 in.

Composition, hundredths %			*UTS*	*YP*	*El*	[illegible]
Cd	Fe	O				
Cu-Cd (G) (5)						
50			17.0	2.4	14	[illegible]
100			20.5	2.4	13	[illegible]
200			22.1	1.81	13	[illegible]
300			22.1	2.44	11	[illegible]
400			21.3	2.44	10	[illegible]
700			15.8	2.5	5	[illegible]
1100			11.0	3.0	5	[illegible]
1400			7.1	3.2	[illegible]	[illegible]

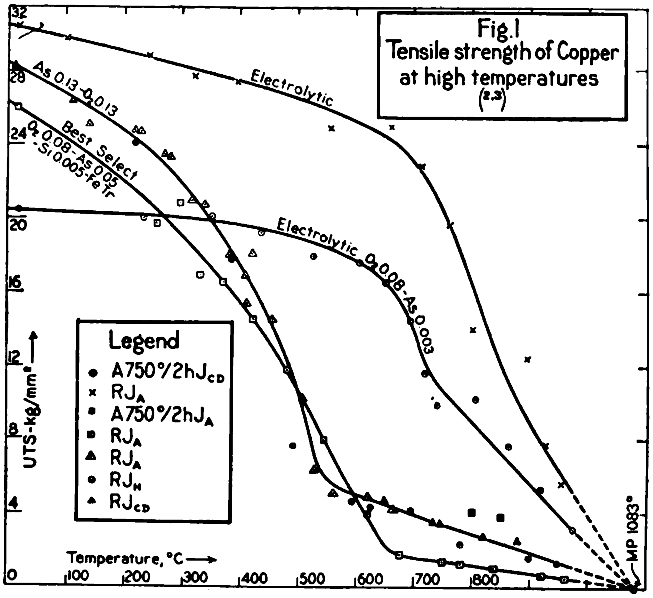


Fig.1 Tensile strength of Copper at high temperatures (2,3)

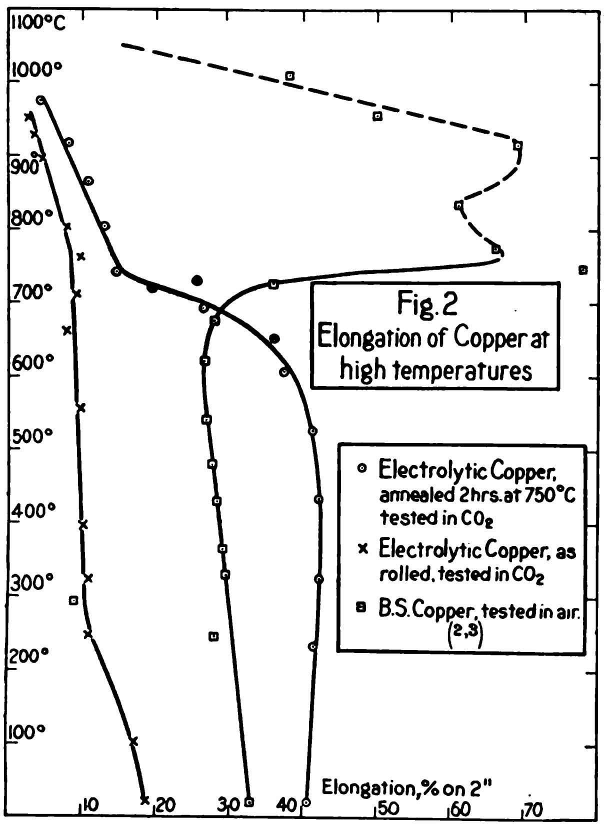


Fig.2 Elongation of Copper at high temperatures

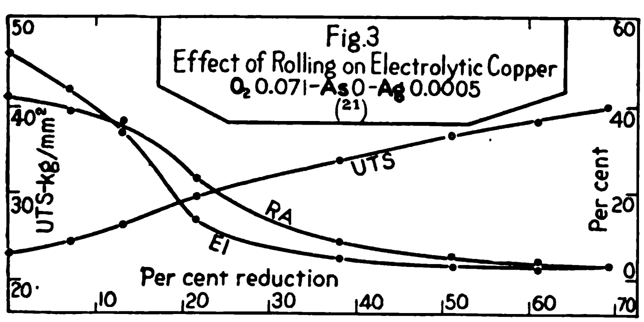


Fig.3 Effect of Rolling on Electrolytic Copper O_2 0.071-As 0-Ag 0.0005 (21)

Composition hundredths %			*UTS*		*El*	*RA*
	Fe	O				
Cu-Fe (RA 700°/30) (10)						
v. also Fig. 5	6	1.4	22.8	(A)	57_5	73
			16.5	(B)	51.7_5	63
	20	0.3	22.4	(A)	60_5	73
	40	0.4	23.6	(A)	60_5	80
			16.9	(B)	50.8_5	68
	73	0.8	26.5	(A)	51.7_5	80
			18.1	(B)	51.4_5	83
	96	0.5	25.2	(A)	45_5	82
			19.1	(B)	42.5_5	88
	138	0.4	30.4	(A)	29.6_5	79
			23.2	(B)	20_5	81
	180	0.7	31.2	(A)	29.0_5	79
			25.7	(B)	24.6_5	82
	209	0.8	34.8	(A)	33.7_5	79
			27.3	(B)	27_5	80

* $\Delta l = -\frac{1}{2}l_0$.

(A) Tested at room temp.
(B) Tested at 250°C.

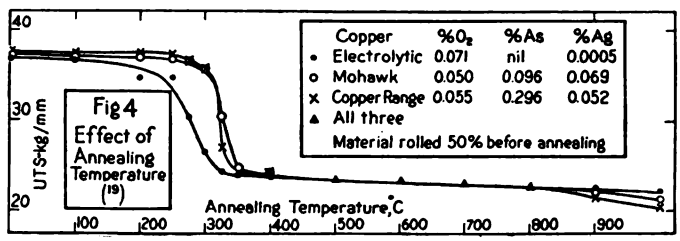


Fig 4 Effect of Annealing Temperature (19)

Composition, hundredths %		Trt	*UTS*	*El*
Mn	P			
Cu-Mn (RA 500° C_s or Q) (21)				
4	1.2	C_s............	32.6	45.5
		Q............	34.2	45
7	1.5	C_s.......... ..	33.2	45
		Q............	34.4	44.5
12	1.4	C_s............	33.9	44.5
		Q............	34.4	44
19	2.1	C_s............	33.6	44
		Q............	34.7	44
29	2.2	C_s............	34.5	44.5
		Q............	34.8	44
40	2.0	C_s............	34.7	44.5
		Q............	35.5	44
61	2.4	C_s............	34.8	44.5
		Q............	35.8	43
98	2.1	C_s............	36.7	44.5
		Q............	37.8	43
134	2.3	C_s............	38.6	42.5
		Q............	40.0	40.5
149	2.6	C_s............	39.1	40.5
		Q............	40.8	40

Cu-O (RA 700°/30) (11)

% O	t,°C	UTS	El	RA
0.04	20	22.57	50	71.4
	250	15.86	58	69.5
0.06	20	22.7	56	70.2
	250	16.27	50.8	65.1
0.09	20	23.2	52.5	64.7
	250	17.05	56.4	67.8
0.17	20	24.20	49.2	56.4
	250	17.2	52	66
0.28	20	24.53	38	42.5
	250	17.0	48.8	58
0.36	20	26.2	34	38
	250	17.8	47.2	62.8

Cu-P (21)

% P	(R)		(RA 500° C_s)		(RA 500° Q)	
	UTS	El	UTS	El	UTS	El
0.014	36.1	4.3	23.0	46.5	24.6	45
.042	38.6	3.9	23.0	46	25.1	44
.092	39.5	3.0	23.5	45	25.1	43
.173	39.6	2.8	24.3	42	25.7	41.5
.399	42.7	3.0	25.4	41	26.2	40
.563	46.4	2.3	26.9	40	28.8	40
1.062	53.4	2.0	28.7	40	31.8	38

Hardness of Cu and Its Alloys with Ag, Cd, Fe, Mn, O, P and Si

% composition	BHN
Cu (electrolytic)	
(G) (11)	28–30*
(Dp) (11)	58–66
Cu-Ag (22)	
A 750–770°/24 h	
Ag 4.2	63
5.5	72
Cu-Cd (G) (5)	
Cd 0.5	55
1.0	65
2–14	66
Cu-Fe (G) (10)	
Fe 0.06	28
.2	28.2
.4	35
.73	44
.96	45
1.38	45
1.80	49.5
2.09	49
Cu-Mn (A) (22)	
Mn 7.2	71.5
15.3	108
31.1	140
Cu-Mn-P† (21)	
RA 500° Q	
Mn 0.04	77
.29	84
.40	77
.61	81
1.34	88
Cu-Mn-P†.—(*Continued*)	
RA 500° C_s	
Mn 0.04	74
.19	74
.29	77
.40	77
.61	81
.98	84
1.34	84
1.49	88
Cu-O (G) (11)	
O 0.015	30
.036	33
.06	34
.08	36
.17	43
.28	53
.36	57
Cu-P (21) R	
P 0.014	96
.042	101
.092	112
.173	118
.399	130
.563	141
1.06	160
RA 500° C_s	
P 0.014	63
.042	65
.092	68
.173	70
.399	74
.563	77
1.06	84

Hardness of Cu and Its Alloys with Ag, Cd, Fe, Mn, O, P and Si.—(*Continued*)

% composition	BHN
RA 500° Q	
P 0.014	74
.042	74
.092	74
.173	74
.399	77
.563	77
1.06	96
Cu-Si (22)	
A 800–900°/1 h	
Si 1.7	59
2.2	71.5
2.6	73
2.7	82
3.8	120

Scleroscope hardness of pure Cu (A), 6–8; (R_c 66%), 22–24 (4, 7).

* 10 mm ball/500 kg load; others 5 mm/500 kg.

† Contains 0.12–0.2 % P.

Specific Gravity* of Copper and Its Alloys with Fe, Mn, P and O

Annealed high conductivity Cu, d_4^{20} = 8.86–8.92 (variable with oxygen content and soundness of ingot) (6, 9, 11, 12). For density of pure Cu, v. p. 456.

Cu-Fe (11)

% Fe	d_4^{20} R	d_4^{20} RA†
0.06	8.92	8.90
.2	8.92	8.92
.4	8.92	8.92
.73	8.92	8.91
.96	8.92	8.91
1.38	8.91	8.91
1.8	8.90	8.91
2.09	8.90	8.90

Cu-Mn-P, **Cu-P** (21)

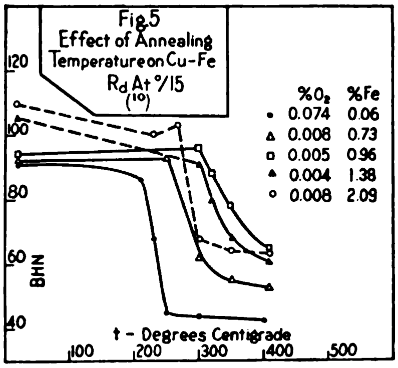
% Mn	% P	d_4^4
0.04	0.012	8.905
.19	.021	8.903
.98	.021	8.860
1.49	0.026	8.820
	0.04	8.945
	.173	8.938
	.399	8.903
	1.062	8.758

Cu-O (11)

% O	d_4^{20} R	d_4^{20} RA†
0.015	8.917	8.912
.016	8.92	8.91
.04	8.907	8.905
.06	8.910	8.901
.09	8.884	8.882
.17	8.825	8.842
.28	8.8	8.8
.36	8.75	8.76

* All specific gravity values for alloys refer to rolled or worked material. Densities of castings mainly unreliable owing to irregular unsoundness.

† R, A 700°/30.



LITERATURE

(For a key to the periodicals see end of volume)

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PROPERTIES OF BRASSES AND OF Pb, Sb, Sn AND THEIR ALLOYS

O. F. Hudson

For specific gravities of the pure metals *v.* p. 456; for compressibilities, *v.* vol. III; for viscosities, *v.* vol. III; for surface tension, *v.* vol. III.

Cu-Zn, Simple Brasses*

% Cu	Trt \ Lit	d_4^{18}† (1)	*BHN* (12, 13)	*ScH* (13)	*UTS* (5, 6, 13-17)	*YP* (13)	*PL* (13)	El_a (6, 13-17)	*RA* (13-15)	*UCS* (5)	*IS*‡ (Izod) (4)	Shr. (18)
90	G_s	8.75	45	12	22			25		21	5.5	2.1
	R_d		120	41	39			5				
	R_s		43	11	25			45				
80	G_s	8.62	45	12	25			30	30	27	6.9	1.87
	R_d		145	50	47			10	30			
	R_s		45	12	28			50	85			
70	G_s	8.50	45	12	28	16		35	35	42	6.2	1.79
	R_d		145	50	47	47	24	15	50			
	R_s		45	12	28	9	6	70	75			
66	G_s		48	13	28			30	30		7.6	2.29
	R_d		145	50	50			15	50			
	R_s		43	16	31			60	70			
65	As rolled, *EL*g = 20; annealed, *EL*g = 6 (from torsion tests) (13)											
60	G_s§	8.40	70	20	36	20		20	25	53	6.2	2.34
	R_d		150	55	47	39	19	35	45			
	R		60	16	39	17	6	55	60			
56	G_s		80		47			20				2.37
	G_m		95									
52	G_s		90		31			10			6.2	2.50
	G_m		85									
50	G_s		95		16			5		77		2.50
	G_m	8.30	90									

Elastic properties of brass, composition not stated: $10^{-2}E$ = 79–92 (G_s); = 92 (R_d); = 100(R_s)(5); $10^{-2}G$ = 36; λ = 0.327(22).

* Mechanical properties of brasses vary widely with condition. Data given are typical of alloys in the indicated conditions.

† For chill castings.

‡ Standard 120 ft. lb. specimens with 11, 23, and 46 ft. lb. tups.

§ *USS* = 24(G) (9); *EL*g = 8.5(R_s) (13).

Effect of Rolling on Hardness of Brass

Cu, 66.65; Pb, 0.3; Fe, 0.08 (24)

γ*	2	4	8	12	15	25	50
ScH	9.7	12.7	15.2	17.3	21.5	27.4	38.2

* γ = Per cent reduction in rolling.

Effect of Annealing on α-Brass

% composition	t_A,°C*	*YP*	*UTS*	El_a	*RA*
Cu, 71; Zn, 28.53; Pb, 0.25; Fe, 0.20; Sn, 0.02 (½ in. diam.)† (15)	(20)	33.9	39.4	35	65
	285	32.9	40.3	35	66
	350	28.8	39.7	38.5	53
	400	25.5	38.7	46	53.5
	500	9.1	32.9	67.5	74.5
	725	6.8	29.1	80	75
	920	5.8	28.7	78	63
Cu, 69.4; Zn, 30.44; Fe, 0.15; Pb, 0.005; Sn, trace (½ in. diam.)† (15)	(20)	49.6	49.9	19.0	65
	320	43.1	51.8	19.5	65.5
	405	17.8	39.5	55	75.5
	500	19.5	36.5		72
	570	15.1	36.9	60	77
	630	10.2	33.1	65	75
	660	10.1	32.3	76.5	80
	702	8.0	31.5	76	77
	765	6.5	31.2	79	70
	808	5.4	29.0	81	75
	900	5.2	27.9	83.5	70

% composition	t_A,°C*	*ScH*	*UTS*	El_a	*RA*
Cu, 66.65; Zn, 23.97; Pb, 0.3; Fe, 0.08 (cross-section 0.5 in. × 0.1 in.)‡ (24)	(20)	34.5	62.5	6	34.8
	350	19.5	40.6	38	54.4
	450	16.3	37.5	48	60
	550	12.8	34.5	58	61.4
	650	9.5	31.6	68	58.4
	750	7.5	29.7	67	56.7

α-Brass (24), composition not stated. R_d, 40%: *UTS* = 53.9; *El* = 11.1. A 200°/30: *UTS* = 55.1; *El* = 10.0.

* Annealed 30 min. at t_A,°C.

† R_d.

‡ 50% reduction.

Annealing Temperatures for Simple Brasses

For 70/30 Brass: A 650 ± 10° gives complete softening and moderate grain size (13).

For 60/40 Brass: A 650° for final treatment but for subsequent hot working, reheat up to *ca.* 800° (13).

For 70/30 or 60/40 Brass: To remove dangerous internal stress, A 250° (28, 29).

Effect of Annealing on *BHN* of R_d α-Brass [2]

Cu, 68.48; Zn, 31.47; Pb, 0.02; Fe, 0.03, annealed 30 min at t_A, °C

t_A,°C \ γ*	20.2	36.6	50.9	59.1
20	110	142	158	163
200	109	148	169	172
250	106	143	166	171
275	104	140	155	154
300	103	137	130	124
325	102	106	93.3	93.3
350	102	100	91.2	91.9
375	88.3	88.8	86.4	88.6
400	82.6	74.6	79.6	83.8
425	75.2	71.2	76.5	79.0
450	75.0	70.5	74.1	77.4
500	70.4	66.2	69.1	69.1
550	65.9	61.3	62.0	62.0
600	61.7	55.4	56.8	57.2
650	55.8	51.5	52.1	52.4
700	50.6	48.9	49.7	49.2
750	46.0	45.9	46.4	46.4
800	43.9	43.1	43.1	44.1
850	41.3	41.1	42.0	41.7

* γ = Per cent reduction in rolling.

Physical Properties of Various Brasses

Composition and treatment		*BHN*	*UTS*	*YP*	El_a	*RA*	Lit.
Cu-Zn-Al, Al-brasses							
Cu, 70.5; Zn, 26.4; Al, 3.1			33.0		50		[5]
Cu, 69.79; Zn, 26.67; Al, 3.54	G	104	39.0	21.3	26.0	27.6	[32]
	F	143	58.2	36.8	34.0	41.9	
Cu, 69.42; Zn, 24.68; Al, 5.90	G	185	59.8	44.1	3.0	1.5	[32]
	F	193	66.6	51.2	6.0	8.4	
Cu, 69.13; Zn, 26.32; Al, 4.55	G	134	50.2	27.7	8.0	11.7	[32]
	F	143	60.8	31.9	17.0	20.0	
Cu, 62.9; Zn, 33.3; Al, 3.8			56.2				[5]
Cu, 59.85; Zn, 37.13; Al, 3.02	G	159	66.1	35.1	18.5	21.5	[32]
	F	154	63.4	28.5	24.5	30.6	
Cu, 59.48; Zn, 39.52; Al, 1.00	G	114	50.4	23.3	30	33.5	[32]
	F	104	49.3	17.5	41.0	44.6	
Cu, 58.26; Zn, 38.56; Al, 2.18	G	138	57.3	25.2	16.0	21.5	[32]
	F	143	58.2	18.4	27.0	33.5	
Cu, 57; Zn, 42; Al, 1	G		40.0		50		[5]
Cu, 55; Zn, 41; Al, 4			60.0		16.5		[5]
Cu-Zn-Fe, Fe-brasses							
Cu, 60; Zn, 38.2; Fe, 1.8	G		40.3	"Aich's metal"			[5]
Cu, 59.37; Zn, 39.68; Fe, 0.95	G	90	42.2	14.8	44	44.6	[32]
	F	107	45.3	21.9	44	63.7	
Cu, 59.12; Zn, 38.36; Fe, 2.52	G	92	41.7	15.7	46	49.7	[32]
	F	110	44.1	24.9	39	54.6	
Cu, 59.04; Zn, 30.95; Fe, 1.56	G	85	42.2	15.7	33	30.6	[32]
	F	98	42.6	21.4	43	59.3	
Cu, 55.04; Zn, 42.36; Fe, 0.83; Sn, 0.83; "Sterro metal"	G		42.5				[20]
	F		53.5				
	D_c		59.8				

Composition and treatment		EL_C	$10^{-3}E$	$10^{-3}G$	Lit.
Cu, 73.85; Zn, 25.90; Fe, 0.25	$H_{1/2}$	18.9	1.186	0.387	[21]
	$H_{1/2}$ A 610°	7.1	1.191	0.408	
Cu, 67.08; Zn, 32.45; Fe, 0.44	D_d	23.9	1.068	0.381	[21]
	D_d A 610°	8.7	1.128	0.410	

Cu-Zn-Mn, Mn-brass

Composition and treatment		*BHN*	*UTS*	*YP*	El_a	*RA*	Lit.
Cu, 59.6; Zn, 38.0; Mn, 2.1	G		41	14	50		[13]
Cu, 57.6; Zn, 41.0; Mn, 1.16	G		42.5	16	50		[12]
Cu, 58.95; Zn, 39.92; Mn, 1.01; Fe, 0.24; Si, 0.05	G	80	39.4	15.9	51	49.7	[32]
	F		41.6	15.9	47	57	

Physical Properties of Various Brasses.—(*Continued*)

Composition and treatment		*BHN*	*UTS*	*YP*	El_a	*RA*	Lit.
Cu, 58.42; Zn, 39.25; Mn, 2.0; Fe, 0.25; Si, 0.05	G	90	40.8	14.3	45	52.7	[32]
Cu, 58.42; Zn, 39.8; Mn, 1.48; Fe, 0.25; Si, 0.05	G	90	40.9	14.0	49	61.5	[32]
Cu-Zn-Mn-Al, etc., High tensile brasses							
Cu, 59.45; Zn, 35.85; Mn, 3.49; Al, 0 98; Fe, 0.22; P, 0.01	G	114	50	28	25	25	[32]
	F	134	55	33	36	47	
Cu, 59.45; Zn, 36.6; Mn, 1.97; Al, 1.56; Fe, 0.40; P, 0.02	G	138	57	27	22	20	[32]
	F	148	58	27	28	30	
Cu, 58.6; Zn, 38.5; Al, 1.5; Mn, 0.5; V, 0.03	D_c		57.3	35.6	12	14	[20]
Cu, 58.15; Zn, 35.18; Mn, 4.10; Al, 2.24; Fe, 0.25; P, 0.08	G	165	63	38	14	15	[32]
	F	159	68	39	18	21	
Cu, 57.23; Zn, 37.9: Al, 2.59; Mn, 2.08; Fe, 0.20	G	165	65	30	18	20	[32]
	F	159	66	31.5	24	25	
Cu, 55.02; Zn, 41.9; Mn, 2.04; Fe, 0.75; Sn, 0.15; Al, 0.09		143	21	53.5	16		[13]
Cu-Zn-Sn-(Fe), Sn-brasses							
Cu, 70; Zn, 29; Sn, 1; "Admiralty condenser tube brass"		Mechanical properties substantially those of 70/30 brass					[13]
Cu, 62; Zn, 37; Sn, 1; "Naval brass"	G		39	19	15	25	[13]
	R_d	19*	50	39	20	30	
	R_s	8*	44	19	35	40	
Cu, 60; Zn, 40; Sn, 0.7–1.1		E = 10 500–13 400 kg/mm²					[27]
Cu, 59.95; Zn, 39.38; Sn, 0.47; Fe, 0.20	G	87	41	17	44	42	[32]
	F	107	46	25	38	60	
Cu, 59.17; Zn, 37.63; Sn, 2.98; Fe, 0.22	G	136	33.4	26.0	1.5	3.2	[32]
Cu, 58.9; Zn, 40.1; Sn, 1.0	G	98	42.5	16	32	34	[32]
	F	107	45.5	22	38	45	
Cu, 58.82; Zn, 38.76; Sn, 2.11; Fe, 0.31	G	114	41	19	13	15	[32]
Cu, 58.7; Zn, 39.6; Sn, 10; Fe, 0.34; Pb, 0.4; "Durana"			40.8	18.0	32	36	[16]
		E = 7 430 kg/mm²					

* These values are for *PL*.

Pb

Treatment		*UTS*	Lit.	*BHN*	$10^{-3}E$	$10^{-3}G$	λ	Lit.
Cast		1.25	[23]	4.2				[7]
Rolled		2.1	[19]		1.5–1.7	0.55	0.43	[5]
Annealed		1.8	[19]		1.80			[35]
Drawn wire	Soft	1.70	[22]		1.73			[35]
	Hard	2.20	[22]					
Pr, A 100°		1.7*	[5]	3.8				[7]

ScH = 2 (ordinary hammer); *ScH* = 3 (magnifier hammer) [31].

For CS = 1.5 kg/mm², $\Delta l = -32\%\ l_0$; EL_C = 0.07 kg/mm² [7].

* El_a = 67%.

Pb-Ba-Ca

(Ba + Ca) 1–2%; "Ulco metal" $\left\{\begin{array}{l} UTS = 9.1 \text{ kg/mm}^2 \\ El = 5\% \text{ on 1 in.} \\ RA = 1\% \end{array}\right\}$ [9].

Ba, 1.30; Ca, 0.79 $\left\{\begin{array}{l} BHN = 31.2_u;\ 26.5_v \\ ScH = 7.5;\ 13.5_m \end{array}\right\}$ [31], where u = 500 kg; v = 1000 kg; m = magnifier hammer.

Pb, *ca.* 97.5; Ba, <2; Ca, <1; Hg, 0.25

t,°C	25	50	100	150	"Frary metal" [8]
BHN	29.6	27.2	20.9	14.0	

Pb-Sb (Cast) [11]

% Sb	*UTS*	*El*	*RA*
0.0	1.25*		
2.6	3.16	15	21.6
3.9	3.71	19	25.0
4.5†	4.36	35.5	34.5
5.0	4.42	28.5	27.5
6.1	4.75	21.8	23.3
7.4	4.96	19.3	21.0
8.1	5.24	21.5	22.1
9.9	5.39	15.5	13.6
12.6	5.17	11.0	10.6
14.0	4.94	8.8	9.3
19.6	4.40	1.8	1.5
24.7	4.26	1.3	0.4

* [23].
† Density = 10.5 [5].

Pb, 92; Sb, 8,* Hard Pb (R) [5]

Thickness, mm	*UTS*	*El*	*ScH*
0.89	3.89	14.8	3–4
1.07	3.82	15.2	3–4
1.27	4.16	19.0	3–4

* Density = 10.71 [5].

Pb-Sb-Sn [33]
v. also Pb-Sn-Sb-Cu

Pb, 88.8; Sb, 7.5; Sn, 3.7	*UTS* = 5.7
83.3 9.8 6.9	8.7
78 7 15	6.23

Pb-Sn

% Sn	Trt	*UTS*	*BHN*	Lit.
0	G	1.25*	4.2	(6)
10			10.1	(34)
20			12.2	(34)
30			14.5	(34)
33.3		7.63		(33)
40			15.8	(34)
50		7.1	18.0	(33, 34)

* [23].

Pb-Sn-Sb-Cu, Bearing Alloys [30]
v. also Pb-Sb-Sn

% composition				d_4^{18}	*BHN*	*UTS*	*El*	*UCS**	YP_C*
Pb	Sn	Sb	Cu						
80	5	15		10.04	25†	7.4	2.8	21.1	5.7
63.5	20	15	1.5	9.33	25‡	8.7	0.0	19.2	6.3
48.5	40	10	1.5		22	7.2	0.0	17.8	5.8

* YP_C at $\Delta l = -0.2\%\ l_0$, *UCS* at $\Delta l = -0.5 l_0$.
† *BHN* = 10 at 100°C.
‡ *BHN* = 11 at 100°C.

Sb

UTS = 1.1 kg/mm² (wire 0.36 mm diam.) [3].
E = 7950 kg/mm², *G* = 2020 kg/mm² (from bending tests on wires) [3].

Sn

Treatment	*UTS*	*El*	*BHN*	CS*	EL_C	Lit.
Rolled	2.5					(19)
Annealed	1.7					
Pr, A 100°	1.9	86	5.0	3.6	0.08	(7)
Cast			5.2	2.8		

E = 4000 − 5500 kg/mm². *G* = 1700 kg/mm² [19].
* $\Delta l = -32\%\ l_0$.

Sn-Pb [23, 33, 34]

% Pb	0	10	20	30	34	40	% Pb	0	37
BHN	5.2	13.3	15.2	15.8	16.7	14.6	*UTS*	2.46	7.64

Composition	*BHN*	*UTS*	*El*	*UCS**	YP_C*
Sn-Pb-Sb-Cu, bearing alloys [30]					
Sn, 80; Pb, 6; Sb, 11; Cu 3	32	9.0	0.0	27.6	5.7
60 28.5 10 1.5	27	7.9	0.0	20.2	6.3
Sn-Sb-Cu, bearing alloys [30]					
Sn, 93; Sb, 3.5; Cu, 3.5	25	3.0	11.6	23.1	5.7
86 10.5 3.5	33	10.2	7	26.8	6.9
78 11 11	37	11.5	0.0	18.0	7.1

Sn, 91; Sb, 4.5; Cu, 4.5: d_4^{18} = 7.34; Sn, 89; Sb, 7.5; Cu, 3.5: d_4^{18} = 7.39.
* YP_C at $\Delta l = -0.2\%\ l_0$, *UCS* at $\Delta l = -0.5 l_0$.

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(For a key to the periodicals see end of volume)

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PROPERTIES OF COMMERCIAL COPPER, ORDINARY, PHOSPHOR, AND ZINC BRONZES AND COPPER-BASE BEARING ALLOYS

S. L. Hoyt

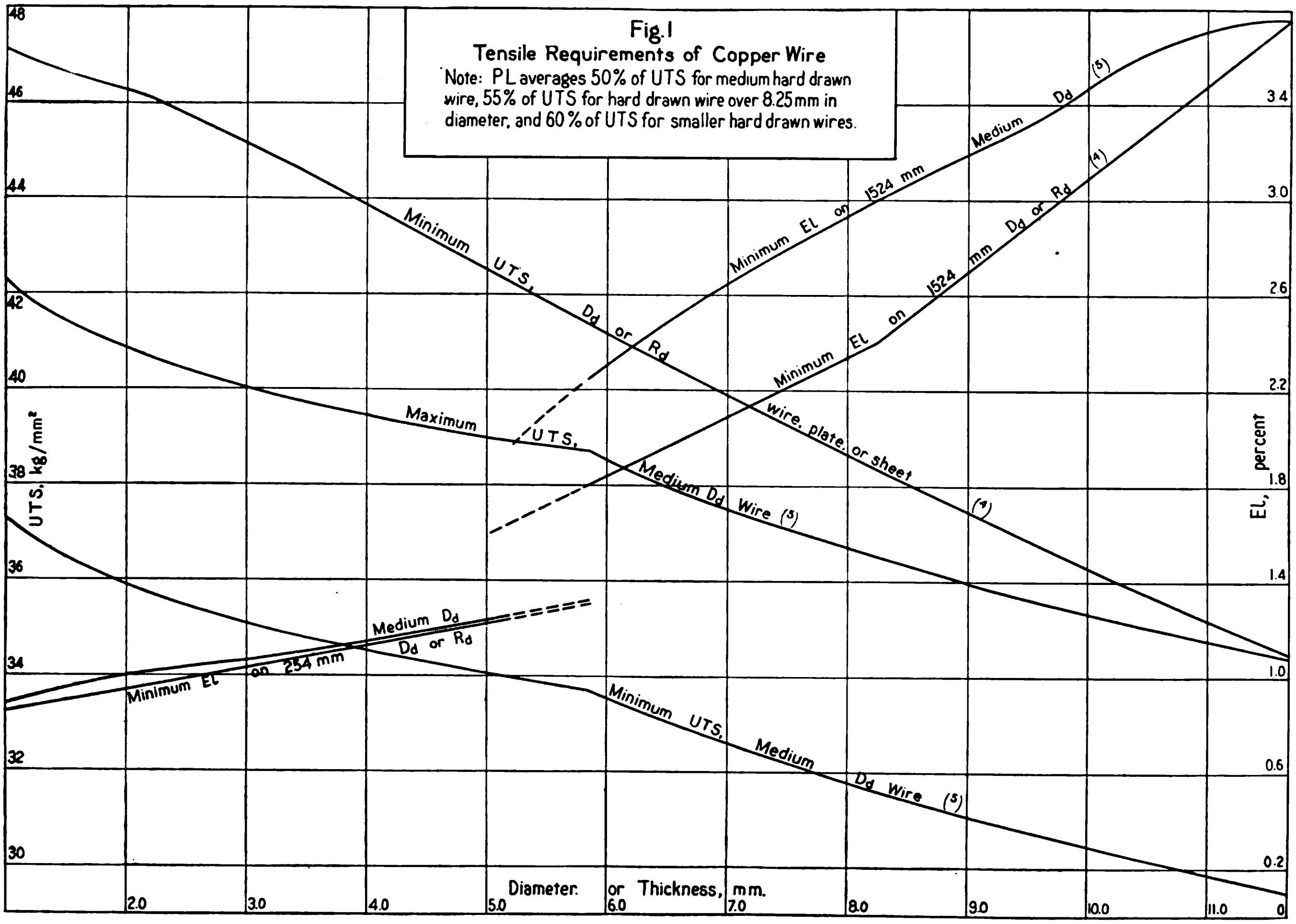
Cu, Commercial Copper

See also Figs. 1 and 2 and p. 552

% Cu	Description and treatment	*UTS*	*PL*	*El*	*RA*	*BHN*	*ScH*	Lit.
99.9	Normalized* pure copper	21–28	†	40–60	40–60	30–40		(13)
	Cast	$14._{2}$		$17._{2b}$				(45)
	Same { A 540°/1 w Q_w	$16._{6}$		$22._{6b}$				
	Same { W *R* Q_w	$18._{0}$		$28._{5b}$				
≮99.5	Pure sheet copper							(46)
	Soft, 0.13–0.79 mm thick	26.0‡		20.0‖				
	Soft, 0.81–9.51 mm thick	25.3‡		25.0‖				
	Hard, 1.83–9.51 mm thick	28.1‖		8.0‖				
	Hard, >9.51 mm thick	26.4‖		15.0‖				
99.6	Cast	17.6	7.0	20	60	40	8	(14)
	Same, R_d 40%	35.2	14.1	5	8	94		
	Annealed at 500°C	24.6		50	60	42	6	
	D_c 50%; *v. also* (36)	35.2	26.0	9			18	
	Cast boronized copper	17.0	8.0	$48._{5}$	74.5			(84)
	Fire-box copper, R, A	23.0		35–38	45–50			(33)
	Special stay bolt Cu, A	27.0		35–38	45–50			

* Best normalised by casting, rolling, drawing, followed by annealing at 500°. † No definite *PL*. ‡ Maximum. ‖ Minimum.

For properties of cold drawn copper wire, *v.* Fig. 2.
For tensile requirements of copper wire, *v.* Fig. 1.



Cu-Sn, Bronze

Cast in graphite mold (45); *v. also* Figs. 3–8

% Sn	Treatment	*UTS*	El_b
2	G_{hm}	19.4	21.8
	A 540°/1 w Q_w	20.3	31.0
4	G_{hm}	22.9	20.5
	A 540°/1 w Q_w	25.2	23.2
	W *R* Q_w	22.6	18.5
6	G_{hm}	24.1	15.3
	A 540°/1 w Q_w	23.8	21.8
	W *R* Q_w	23.9	20.0
8	G_{hm}	28.8	11.5
	A 540°/1 w Q_w	24.9	25.1
	W *R* Q_w	25.9	20.5
10	G_{hm}	29.5	12.7
	A 540°/1 w Q_w	30.4	36.4
	A 400°/1 w C_f	28.6	24.7
	W *R* Q_w	31.4	21.0
13	G_{hm}	29.0	5.1
	A 540°/1 w Q_w	31.7	32.8
	A 400°/1 w C_f	26.8	10.0
	W *R* Q_w	29.5	8.3
	W 620° Q_w	33.3	17.5
16	G_{hm}	27.8	1.5
	A 540°/1 w Q_w	35.2	19.6
	A 400°/1 w C_f	28.6	2.0
	W *R* Q_w	41.4	9.5
	W 620° Q_w	38.3	9.0

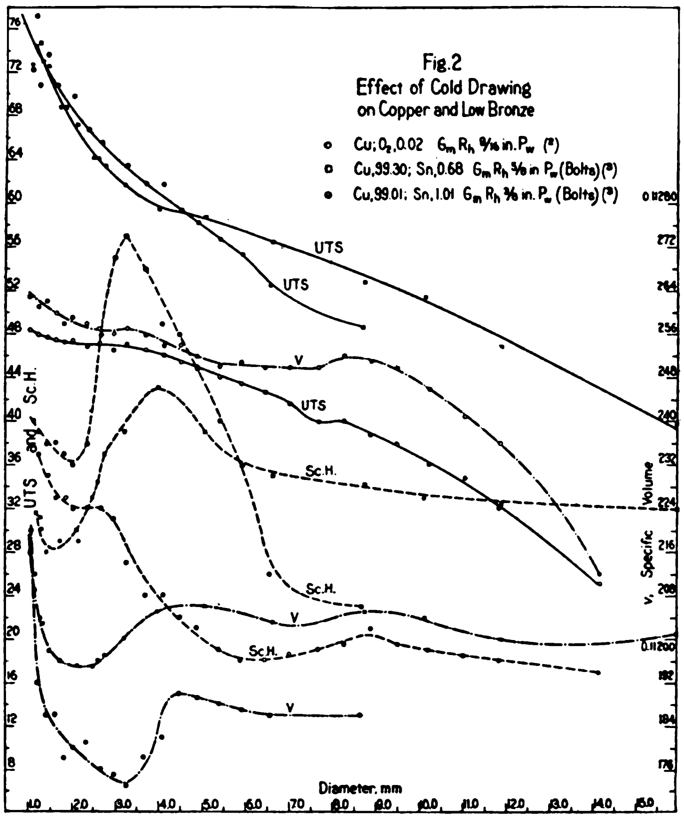
Cu-Sn, Bronze.—(*Continued*)

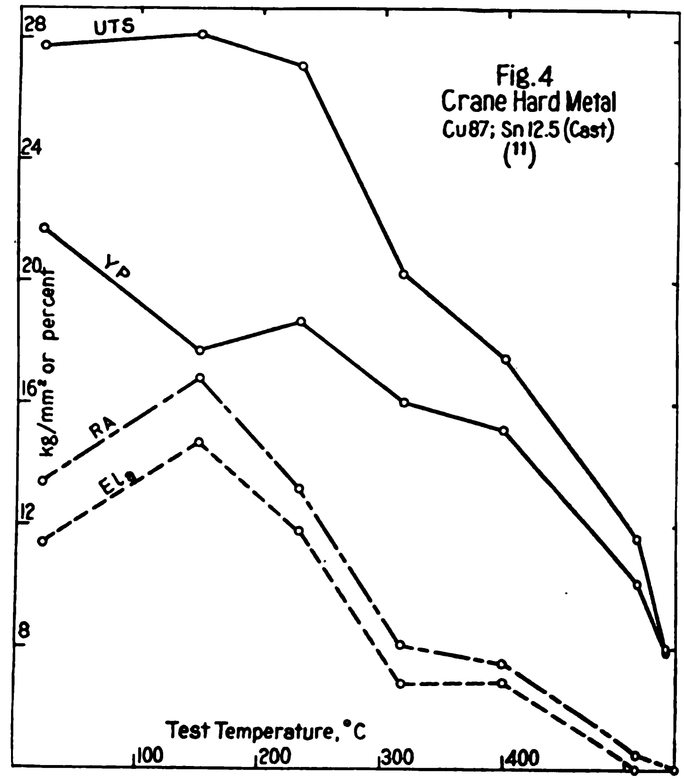
Cast in graphite mold (45); *v. also* Figs. 3–8

% Sn	Treatment	*UTS*	El_b
19	G_{hm}	37.7	2.9
	G C_a	26.3	0.3
	G_m (cold)	23.0	0.2
	A 540°/1 w Q_w	38.7	
	A 400°/1 w C_f	28.5	0.5
	W *R* Q_w	44.1	6.3
	W 620° Q_w	47.0	6.5
	W 720°/45 Q_w	45.7	5.0
22	G_{hm}	31.6	0.4
	A 540°/1 w Q_w	39.1	
	A 610°/1 h Q_w	40.0	5.3
	A 400°/1 w C_f	17.6	
	A 400°/1 h C_a	Cracked	
	W 700° C_a	12.4	0.05
	W *R* Q_w	44.5	1.3
	W 700° Q_w	39.9	1.0
25	G_{hm}	9.9	Nil
	A 540°/1 w Q_w	17.7	
	A 400°/1 w C_f	11.7	
	W 630°/1 h Q_w	22.2	0.8
	W 600°/1 h Q_w	25.8	0.4
	W 700°/1 h Q_w	23.6	1.1
30	G_{hm}	11.1*	
	A 400°/1 w C_f	2.5*	

* Some specimens of this composition broke while being gripped.

For properties of cold drawn bronze, *v.* Fig. 2.





Cu-Sn-P, Phosphor Bronze

See also Figs. 9 and 10

% Sn	% P	Index No.	Treatment	*UTS*	Y = *YP* P = *PL*	*El*	*RA*	*BHN*	*ScH*	Lit.
3.77	0.16		D (rod)	56.0	41.7_Y	17.5	57			(42)
4	Tr.		G	23	11_Y	15–20		50–60		
			Wk	39						
			Wk, A	31.5						
			R_c, A	32			80			
			D	84–112						
			D, A	28–35						
4.7*	Tr.		G_s	24.3	5.7_P	22	18.2	56.8	20.4	(42)
	1.2		G_m	34.1	6.0_P	12.7_5	12.4	69.1	16.2	
4.9	0.1		R	45.7	28.2_P	30.0			37	(14)
6	Tr.		G	23	11_Y	15–20				
			D	84–112						
			D, A	28–35						
10†	0.4		G_s	20.9	6.3_P	6.0	8.5	70	21	(42)
			G_m	23.8	5.0_P	4.0	4.9	84	20	
10	Tr.		G	23	$12.5–14_P$	15–20	10–17			(18)
			G_{om}	30						
10–12	0.1–0.3	612	G	24.6	14.1_Y§	10§				(47)
11	0.3	1359	G	24.6–28.4	$15.8–17.3_Y$	6–10	7–9	80		(56)
15‡	0.6		G_s	17.6	8.5_Y	3.0	1.8	80	25	(42)
			G_m	23.6	9.5_Y	1.0	1.5	94	24	

* Malleable, typical analysis: Cu, 94.0; Sn, 4.7; P, 1.17; As, 0.15; Pb, 0.11; (Sb, Fe, Al, Zn), Tr.

† Typical analysis: Cu, 89.8; Sn, 9.3; P, 0.44; As, 0.39; Pb, 0.03; (Sb, Fe, Zn), Tr.; Al, 0.

‡ Typical analysis: Cu, 84.8; Sn, 14.3; P, 0.6; Sb, 0.15; Fe, 0.1; Pb, 0.08; As, 0.06.

§ Minimum.

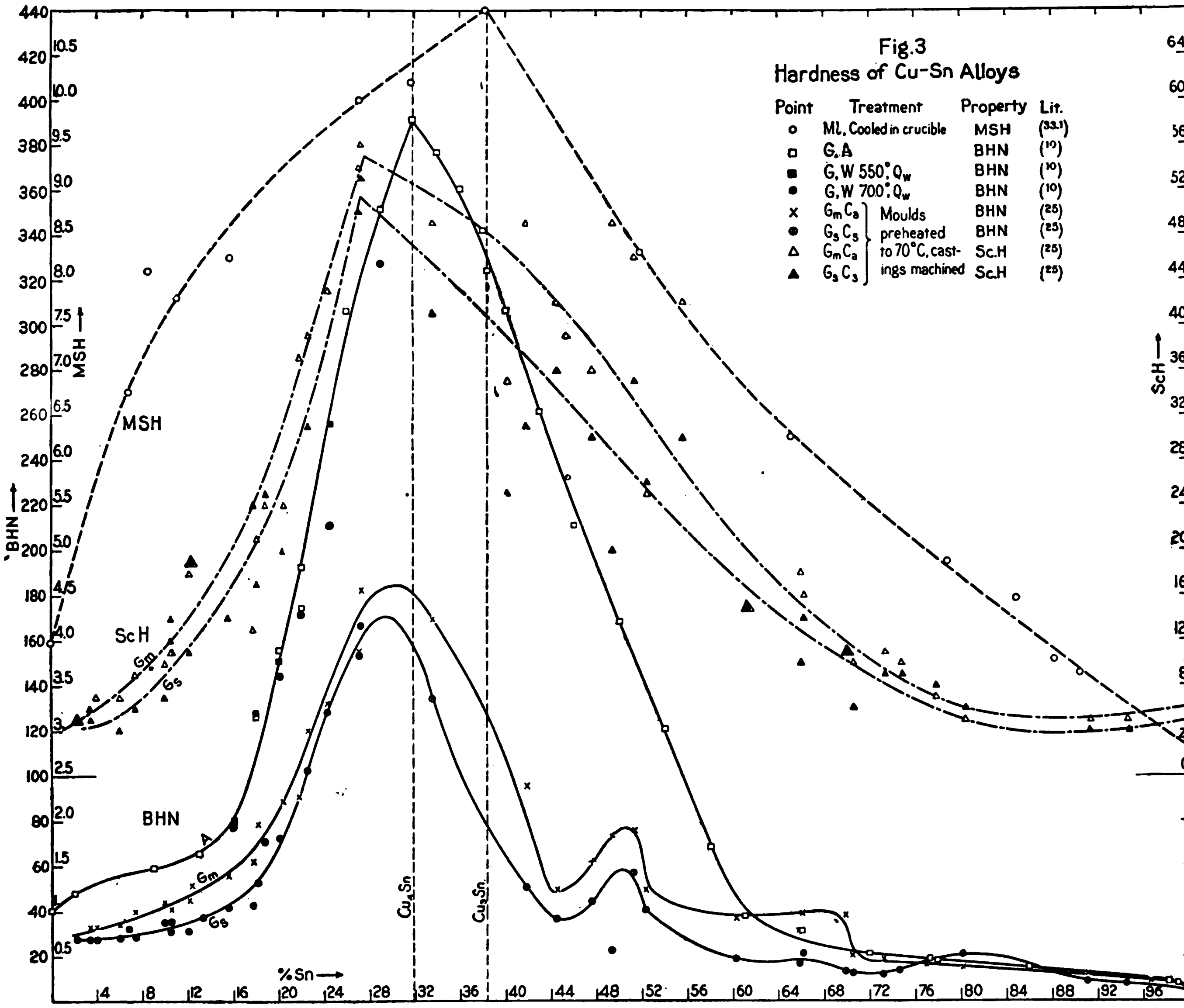


Fig. 3
Hardness of Cu-Sn Alloys

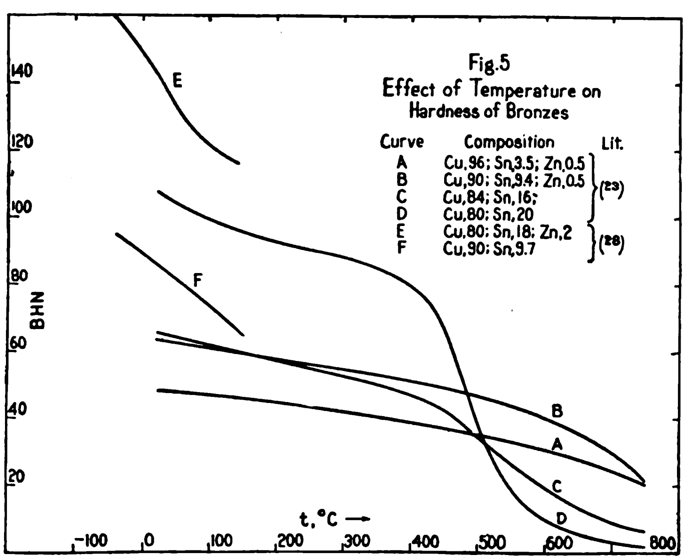


Fig. 5
Effect of Temperature on Hardness of Bronzes

Mechanical Properties of Copper-Base Bearing Alloys as Cast (Car Journal Bearings) (16)

% compositon				UTS	El_a	PL_C	ε at 70.3 kg/mm²	ScH
Cu	Sn	Pb	Zn					
95	5			29.4	34.5	12.7	31	23
90	5	5		28.5	34.5	13.4	32	15
	10			27.4	15	17.6	26	23
85	5	5	5	26.8	36	12.7	33	14
	5	10		22.0	19.5	12.7	36	14
	10	5		23.0	9.5	15.5	26	19
80	5	5	10	19.8	15	12.7	32	16
	5	10	5	24.4	23	11.3	34	18
	5	15		16.4	15.5	11.3	39	14
	10	5	5	23.6	3.5	19.0	21	21
	10	10		22.4	8.5	16.2	29	21
75	5	5	15	19.0	10	12.0	28	18
	5	15	5	22.0	19	13.0		19
	5	10	10	21.0	13	13.4	32	18
	5	20		16.4	15.5	10.5		12
	10	5	10	17.2	1.0	19.0	19.5	25
	10	10	5	22.0	2.5	20.0	22	21
	10	15		19.0	6	16.2	32	15
70	5	25		17.4	14	11.6		12
	5	10	15	20.0	10	13.0	30	20
	5	20	5	19.8	20	12.3		15

Mechanical Properties of Copper-Base Bearing Alloys as Cast (Car Journal Bearings) (16).—(*Continued*)

% composition				*UTS*	El_a	PL_C	ϵ at 70.3 kg/mm²	*ScH*
Cu	Sn	Pb	Zn					
70	10	20		19.0	6	14.8		19
	10	5	15	19.3	1.5	28.1	17	28
	10	15	5	19.8	1.5	18.3		23
	10	10	10	21.1	4.7	20.4	17	22
65	5	30		13.9	12	10.5		10

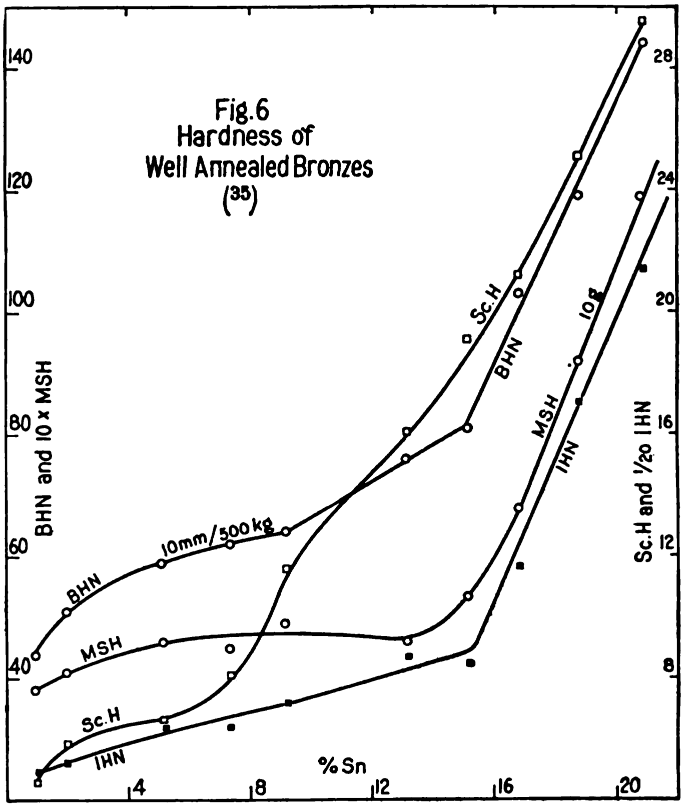


Fig. 6 Hardness of Well Annealed Bronzes (35)

Wear and Frictional Properties of Copper-Base Bearing Alloys

Mean values from service tests on the Pennsylvania R. R. (21.1)

% composition					Index No.	Relative wear
Cu	Pb	Sn	P	As		
89.2		10.0		0.8		1.42
87.5		12.5				1.47–1.53
79.7	9.5	10.0	0.8		1326	1.00
79.7	9.5	10.0		0.8		1.01
79.2	7.0	10.0		0.8		1.15
77.0	12.5	10.5			556	0.92–0.93
77.0	15.0	8.0			553	0.865

Laboratory Tests on the Carpenter Machine* (16)

% composition				Friction, kg	Temp. rise, °C	Wear in mg	Relative wear†
Cu	Pb	Sn	Zn				
95.0		4.95		7.3	29	4.96	0.49
90.7		9.45		5.9	28.5	11.45	1.13
85.8		14.9		5.9	28	18.14	1.79
90.8	4.8	4.6		6.4	29.5	3.51	0.35
85.1	10.6	4.6		8.4	31	2.46	.24
81.3	14.1	5.2		8.4	32	2.12	.21
75?	20?	5?		8.4	32	1.80	.18
68.7	26.7	5.2		8.2	32	1.32	.13
64.3	31.2	4.7		8.2	35.5	0.84	.08
83.3	10.3	5.3	2.1	8.4	38	2.69	0.27
79.8	10.3	4.7	5.4	8.4	36.5	3.02	.30
77.4	11.4	5.6	6.5	8.4	38	3.06	.30
74.3	10.5	4.7	11.0	8.4	38.5	5.48	.54

* Total number of revolutions = 100 000; speed = 525 r.p.m.; bearing 3¾ in. diam. × 3½ in. long; load = 0.7 kg/mm²; lubrication, Galena coach oil fed by cotton waste.

† Comparison with above results on basis of (21.1) according to which wear of Cu-Sn is approximately proportional to Sn content, more exactly to % of δ constituent.

Cu-Pb-Sn, Mechanical Properties of Bearing Bronzes (As Cast)

See also Fig. 11

% composition						Index No.	*UTS*	*El*	*RA*	*BHN*†	*UCS*	DL_C	CS	ϵ	Lit.
Cu	Pb	Sn	Zn*	P	S*										
85	5	10	0.25	0.70‡	0.05	211	19.7	12.5_a		60		12.6§	70.3	26	(6,33)
80	10	10	0.50	0.70‡	0.05	212	17.6	8_a		55		10.5§	70.3	29	(6,33)
80	10	10	2.00	0.05*	0.05	213	15.5	8_a		50		8.8§			(6)
79.7	9.5	10		Tr.			16.8	2.9‖		55.0					(21.1)
79.7	9.5	10		0.8		1326	21.1	6							(33)
77	15	8	0.50	0.25*	0.05	214	14.1	10_a		48		8.4§			(6)
77	15	8	0.2			553	16.9	11				14.8			(21.1,33)
73	20	7	0.50	0.05*	0.25	215	12.7	7_a		45		7.7§			(6)
70	20	10			*ca.* 1	55					64.6	16.2			(3.1)
70	25	5	0.50	Nil	0.25	216	10.5	5_a		40		7.0§			(6)
67	24	9			*ca.* 1	55					56.8	21.8			(3.1)
64.75	30	5				456	12.2	6.5‖		41.3					(33)
64	30	5		Ni, 1.0		34	15.0	10.1_a	8.20	40.0			45.3	44	(33)
62.5	30	7.5		S, *ca.* 1		55					53.7	13.7			(3.1)
60.67	32.97	4.60		Ni, 2.1		469	12.8	3.0_a	0.35	52.0			39.5	30.4	(33)
58.5	35	6.5		S, *ca.* 1		55					45.0	10.5			(3.1)
55	40	5		S, *ca.* 1		55					31.9	9.8			(3.2)
50	50									21.8					(33)

* Maximum in the alloys of (6), also: Fe, ≯0.25; Sb, ≯0.50; Al, 0.

† 10 mm, 500 kg; *v. also infra.*

‡ Minimum.

‖ On 8 in.

§ Load producing ϵ = 0.1 % in specimen 1 in.² cross-section by 1 in. long.

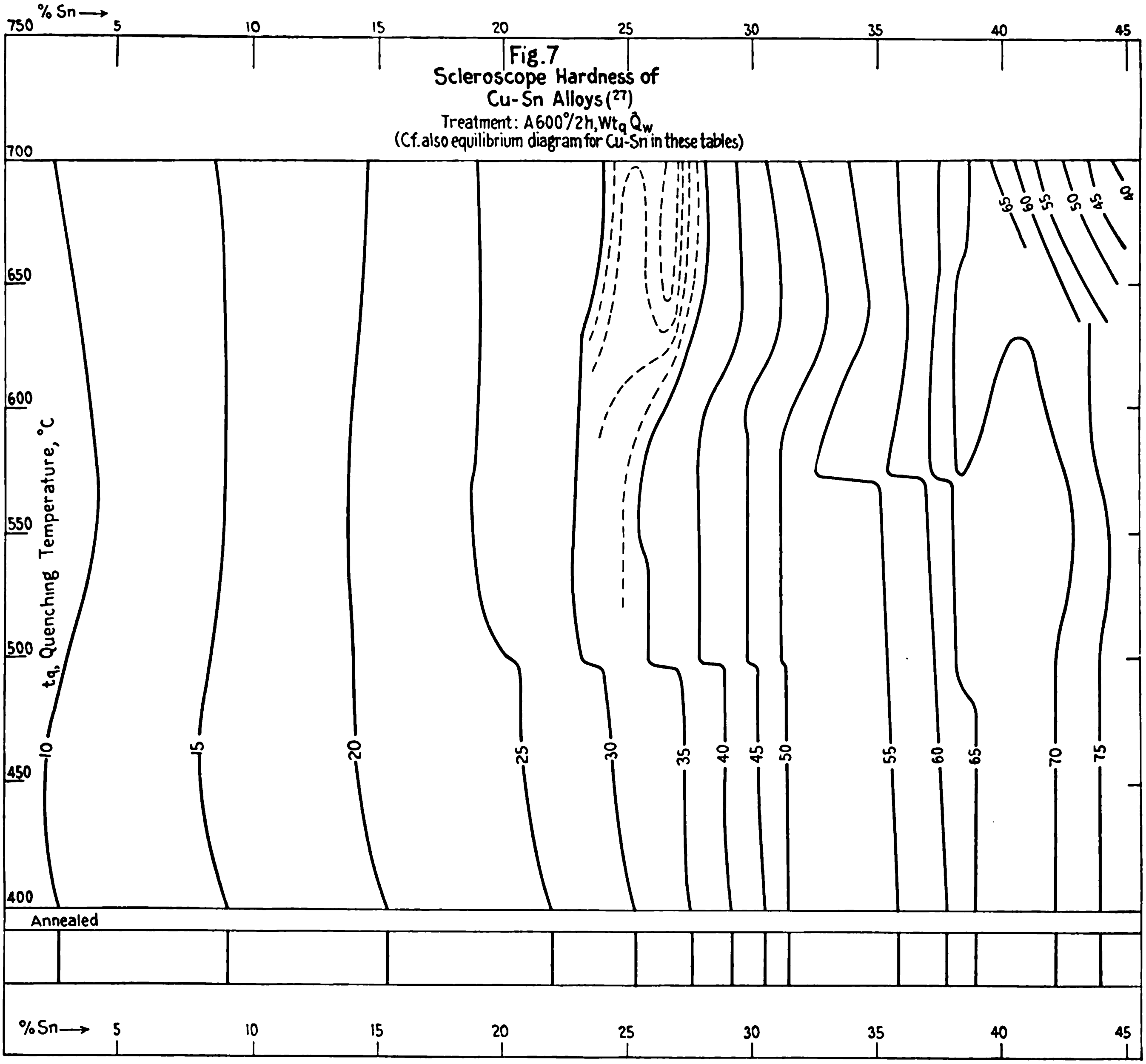


Fig. 7
Scleroscope Hardness of Cu-Sn Alloys (27)
Treatment: A 600°/2h, Wt_q $\hat{Q}_w$
(Cf. also equilibrium diagram for Cu-Sn in these tables)

Cu-Sn-Zn, Zinc Bronze

See also Fig. 12

% composition			Treatment	*UTS*	*YP*	*PL*	*El*	*RA*	*BHN*	*ScH*	Lit.
Cu	Sn	Zn									
90	6	4	D_c, 3.5–3 mm diam	57.3			9.5				(53)
			D_c, A 400° 1 h C_a	53.1			17.3				
			D_c, A 600° 1 h C_a	38.4			51.8				
			D_c, A 800° 1 h C_a	32.7			51.3				
			D_c, A 400° 1 h Q_w	52.3			22.0				
			D_c, A 600° 1 h Q_w	39.3			51.3				
			D_c, A 800° 1 h Q_w	34.0			51.0				
90	9.5	0.5	G	22.5							
88	8	4	G_s at 1100–1140°	30.4		8.4	36_a	28.0			(49)
88	8	4*	G	23–26	14–17.5		25–30		55–75		(18)

Continued on p. 565.

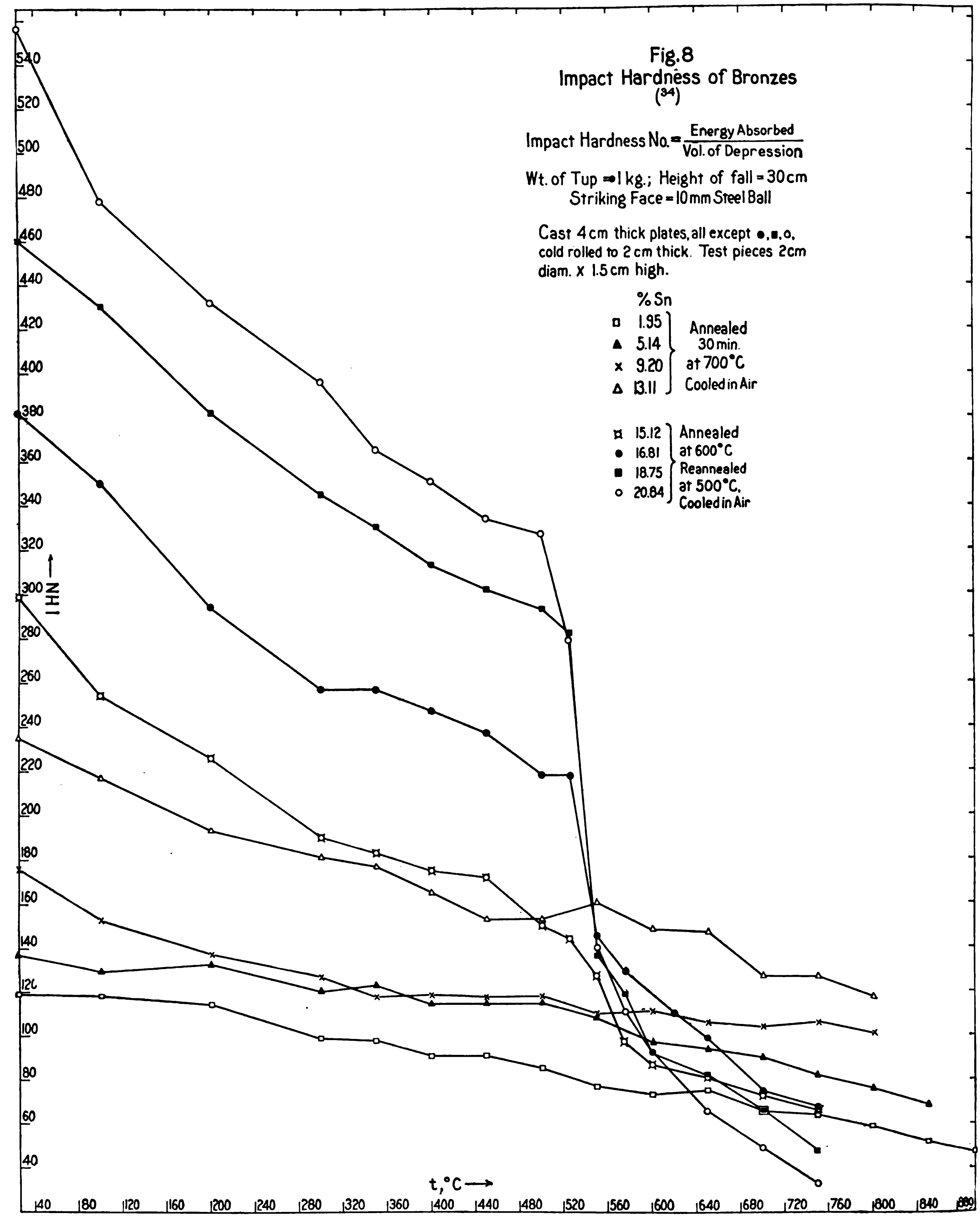
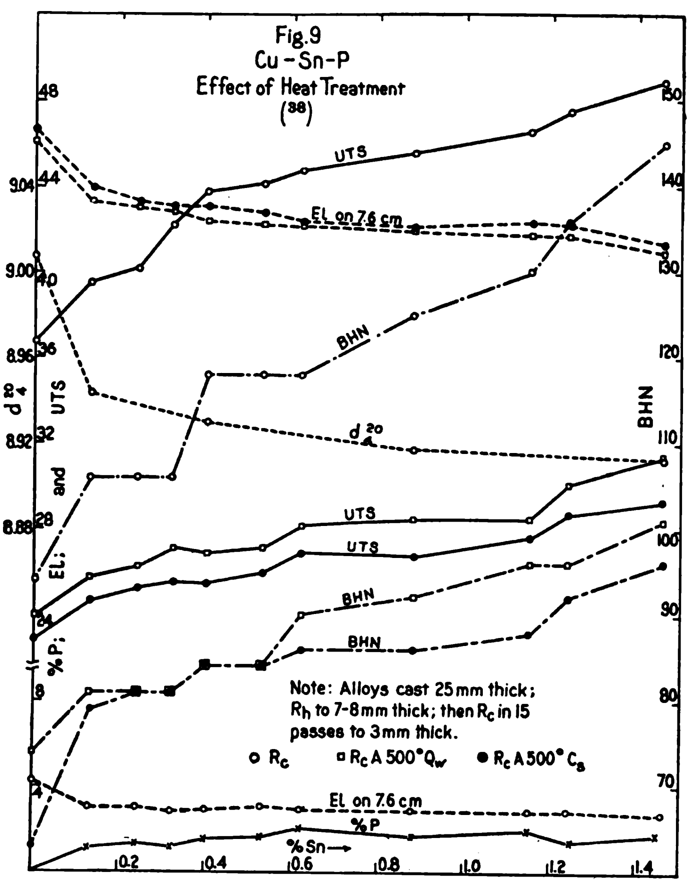


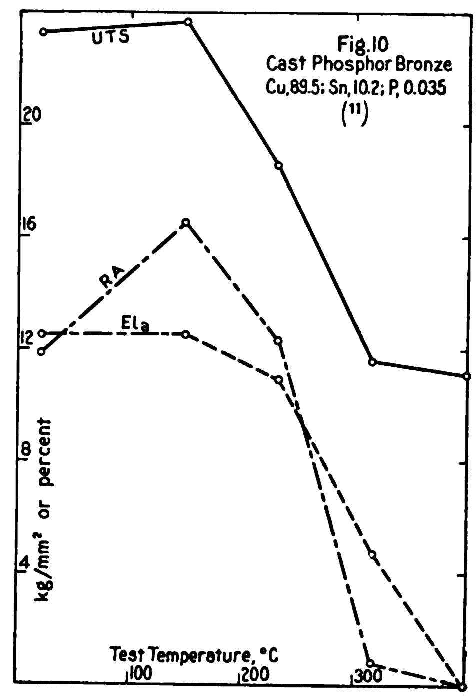
Fig. 8
Impact Hardness of Bronzes
(34)
Impact Hardness No. = Energy Absorbed / Vol. of Depression
Wt. of Tup = 1 kg.; Height of fall = 30 cm
Striking Face = 10 mm Steel Ball
Cast 4 cm thick plates, all except ●, ■, o, cold rolled to 2 cm thick. Test pieces 2 cm diam. x 1.5 cm high.
% Sn
1.95
5.14
9.20
13.11
Annealed 30 min. at 700°C Cooled in Air
15.12
16.81
18.75
20.84
Annealed at 600°C Reannealed at 500°C, Cooled in Air
IHN
t, °C

Cu-Sn-Zn, Zinc Bronze.—(*Continued*)
See also Fig. 12

% composition			Treatment	*UTS*	*YP*	*PL*	*El*	*RA*	*BHN*	*ScH*	Lit.
Cu	Sn	Zn									
88	10	2	G_s at 1200°	26.8	16.4		14.0		77	16	(40)
			Ml_2, G_s at 1200°	26.8	14.0		17.2		79	14	
			G_s at 1060°†	24.6			28.0		62		(39)
			G_m at 1060°	23.6			4.0		86		
			G_s	30	11–12.5						(46)
			G (U. S. N. Spec. G)	24.7	13.7	7.4	22.5	23.1			(17)
			G (U. S. N. Spec. Pc-2)	25.8	12.5	7.2	25.5	31.7			
For effect of heat treatment on this alloy *v. infra.*											
87	8	5	G_s at 1200°	26.5	13.1		18.7		80	18	(41)
			Ml_2, G_s at 1200°	24.4	13.1		15.6		83	19	
86	9	5	G_s	16–24			2.5–8		55–75		(20, 21)
			G_m	16–22			2.5–8		75–90		
86	13	1*	G	26	14–17.5		4–8		85–120		(18)
85	5	10	G_s at 1200°	25.2	12.3		25.0		69	15	(41)
			Ml_2, G_s at 1200°	24.4	12.1		23.4		69	15	

* Contains trace of P. † In dry sand.





Effect of Casting Temperature and Heat Treatment of Cu, 88; Sn, 10; Zn, 2

"Admiralty bronze," "U. S. Government bronze Spec. G;"*
v. also Fig. 12

Treatment		*UTS*	El_a	*RA*	*BHN*	Lit.
Cast in dry sand at:	1050°	29.7	20.5	13.5		(39)
	1120°	30.9	20.5	14.0		
	1220°	28.1	17.0	16.2		
	1255°	28.0	15.5	13.0		
Chill cast at:	1120°	34.7	5.5	4.0		(39)
	1220°	34.9	6 0	7.0		
	1255°	23.9	15.0	12.1		

Treatment			*UTS*	El_a	*RA*	*BHN*	Lit.
G_s (dry sand)† at ... *ca.* 1060°			24.6	28.0		62	(39)
Same heated slowly to	500°	Q_w	12.9	12.0		77	
	600°		10.2	7.5		65	
	700°		7.7	3.0		61	
	800°		14.2	5.5		74	
G_s to size‡			30.2	11–12.5			(46)
Same heated 30 min at:	495°	Q_w	31.2	9.4			
	540°		31.7	15.6			
	595°		33.7	20–22			
	650°		13–16.6	4.7–11			
	705°		13–17.5	8–11			
	760°		11.7	6.5–7.5			
G_s, heated 30 min at:	495°	Q_o	26.1	9.4			(46)
	540°		31.3	18.8			
	595°		33.5	28.0			
	650°		26.7	28.0			
G_s, heated 30 min at:	495°	C_a	29.3	9.4			(46)
	540°		33.7	26.5			
	595°		35.8	53.0			
	650°		30–35.5	25–50			

Effect of Casting Temperature and Heat Treatment of Cu, 88; Sn, 10; Zn, 2.—(*Continued*)

Treatment		*UTS*	El_n	*RA*	*BHN*	Lit.
G_s†		27.1	24.0		63	(39)
Same annealed 30 min at:§	500°	23.8	26.5		65	
	600°	25.7	28.5		61	
	700°	28.4	37.5		60	
	800°	24.4	31.0		60	
Sand cast, annealed 30 min at: (C_f > 24 h)	495°	26–29	12.5–15.5			(46)
	540°	32.0	18.8			
	595°	31.0	37.5–81			
	650°	29.8	28.0			
	705°	32.5–35	37.5–50			
	760°	29.5–31	32.9			
Chill cast		23.6	4.0		86	(29)
Same annealed 30 min at:	500°	19.4	7.5		80	
	600°	30.9	25.0		75	
	700°	31.5	30.0		74	
	800°	27.1	22.5		70	
Chill cast		25.2	6	7		(39)
Same annealed 30 min at:	500°	24	7.5	16		
	600°	27	19	19		
	700°	28–35	26	22		
	800°	19	17	18		

* For effect of other casting conditions, v. (4).

† Specimens ⅝ in. diam. × 2 in. gage length, machined before heat treatment.

‡ Gaged portion: 0.5 in. diam.

§ Gradually heated to t,°C, cooled at moderate rate to 400°C, then cooled slowly.

Cu-Sn-Zn-As, Effect of Adding As to Admiralty Gun Metal (17)

% composition						t_c, °C*	Trt†	*UTS*	*YP*‡	El_a§
Cu	Sn	Zn	As	Pb	Fe					
88.14	9.97	1.67	0.04	0.08	0.07	1220	G_s	27.3	15.4	16.7
						1250	G_m	22.8	18.7	4.5
88.20	10.28	1.34	.04	.08	.05	1240	Ml_2G_s	23.8	15.8	11.0
						1280	Ml_2G_m	23.0	16.5	4.3
87.74	10.30	1.39	.42	.08	.05	1220	G_s	26.3	15.0	9.0
						1250	G_m	23.8	18.3	4.5
87.98	10.35	1.08	.42	.08	.08	1250	Ml_2G_s	23.9	15.1	11.0
						1280	Ml_2G_m	23.2	17.0	3.4
88.20	9.89	0.58	1.01	.12	.12	1220	G_s	23.5	15.5	7.8
						1240	G_m	23.9	18.7	5.0
88.35	9.86	0.49	1.01	.12	.12	1240	Ml_2G_s	24.2	15.5	10.1
						1280	Ml_2G_m	23.6	17.6	3.8

* t_c = casting temperature.

† Bars cast vertically 1 in. diam. × 15 in. long; sand cast ones in green sand. All molds preheated. ‡ By dividers.

§ Test piece diameter = 0.798 in. All values in this table are means from two test pieces.

Cu-Sn-Zn-Pb, Effect of Adding Lead to Zinc Bronzes (49)

% composition				t_c, °C*	Trt	*UTS*	*PL*	*El*†	*RA*
Cu	Sn	Zn	Pb						
88	10.0	2	0	1100–1140	G_s	30.3	9.2	29.7	24.3
88	8.0	4	0	1100–1140	G_s	30.4	8.4	36.0	28.0
90	6.5	3	0.5	1090–1125	G_s	28.6	9.6	37.6	34.1
				1170–1200	G_s	26.4	9.1	28.1	29.7
				1090–1200	A‡	25.1	9.3	24.9	23.2
90	6.5	2	1.5	1080–1136	G_s	28.6	8.6	35.3	31.8
				1170	G_s	25.2	7.3	25.5	32.5
				1080–1170	A‡	29.0	9.6	37.2	33.6
90	6.5	1	2.5	1100–1140	G_s	27.8	9.3	27.2	27.7
				1150–1200	G_s	23.6	8.7	18.6	19.7
				1100–1200	A‡	24.4	9.8	20.1	23.5
90	5.5	4	0.5	1060–1120	G_s	26.6	8.7	29.3	30.4
				1160–1180	G_s	26.5	8.1	31.6	32.4
				1060–1180	A‡	26.1	9.3	24.2	27.3
90	5.5	3	1.5	1060–1140	G_s	25.4	7.5	31.4	28.4
				1160–1180	G_s	21.7	6.8	22.8	18.6
				1060–1180	A‡	25.7	8.4	28.5	26.7
90	5.5	2	2.5	1100–1120	G_s	25.2	7.6	23.9	22.6
				1160–1180	G_s	23.7	7.0	23.3	23.4
				1240–1260	G_s	20.9	6.7	15.5	16.6
				1100–1260	A‡	23.5	7.3	22.2	22.8
90	4.5	5	0.5	1100–1140	G_s	24.4	6.4	29.4	25.3
				1150–1180	G_s	23.0	6.5	27.4	24.4
				1100–1180	A‡	22.6	6.7	28.8	21.9
90	4.5	4	1.5	1100–1140	G_s	23.6	6.3	26.5	22.9
				1180	G_s	20.2	5.8	18.3	18.8
				1100–1180	A‡	22.3	7.2	24.2	20.6

* t_c = casting temperature.

† Shoulder type test piece 0.505 in. diam. × 2 in. gage length.

‡ W 600°/30 C_f >12 h.

Cu-Sn-Zn-Pb-As, Effect of Adding Pb to Arsenical Admiralty Gun Metal (41)

% composition*						t_c, °C†	Trt‡	*UTS*	*YP*§	El_a‖	*BHN*¶	*ScH*
Cu	Sn	Zn	As	Pb	Fe							
87.72	9.97	1.54	0.48	0.17	0.08	1210	G_s	23.3	16.4	11.5	74	8.5
						1210	G_m	26.9	16.7	5.0	91.0	9.0
88.23	10.04	0.98	.47	.18	.05	1220	Ml_2G_s	26.8	13.7	15.0	74	8.5
						1220	Ml_2G_m	24.7	17.5	5.0	92.0	9.0
87.30	10.05	1.16	.50	.86	.07	1220	G_s	24.7	15.2	12.5	70	7.0
						1220	G_m	24.7	18.0	4.5	87.6	8.0
87.84	10.00	0.72	.47	.91	.04	1210	Ml_2G_s	27.6	15.9	16.5	71	7.5
						1210	Ml_2G_m	25.0	16.8	5.5	91.0	8.0
86.58	10.04	1.33	.48	1.46	.06	1220	G_s	25.0	15.4	15.0	66	6.0
						1220	G_m	22.5	16.0	3.5	82.6	7.0
87.39	9.95	0.62	.48	1.48	.05	1210	Ml_2G_s	27.6	14.6	19.5	69	7.0
						1210	Ml_2G_m	21.9	15.4	3.5	85.0	7.0
86.23	10.12	1.42	.47	1.68	.06	1200	G_s	24.9	14.8	10.5	69	7.0
						1200	G_m	22.5	17.2	2.5	89.0	7.5
86.27	10.17	1.30	.49	1.67	.06	1230	Ml_2G_s	25.5	12.9	13.5	69	8.0
						1230	Ml_2G_m	23.3	15.1	3.0	89.0	8.0

* All alloys contain traces of Sb and Ni.

† t_c = casting temperature.

‡ G_s in green sand, all molds preheated. Castings 1 in. diam.

§ By dividers (extension = 0.01 in.).

‖ Test piece diameter, 0.798 in.

¶ 10 mm, 500 kg.

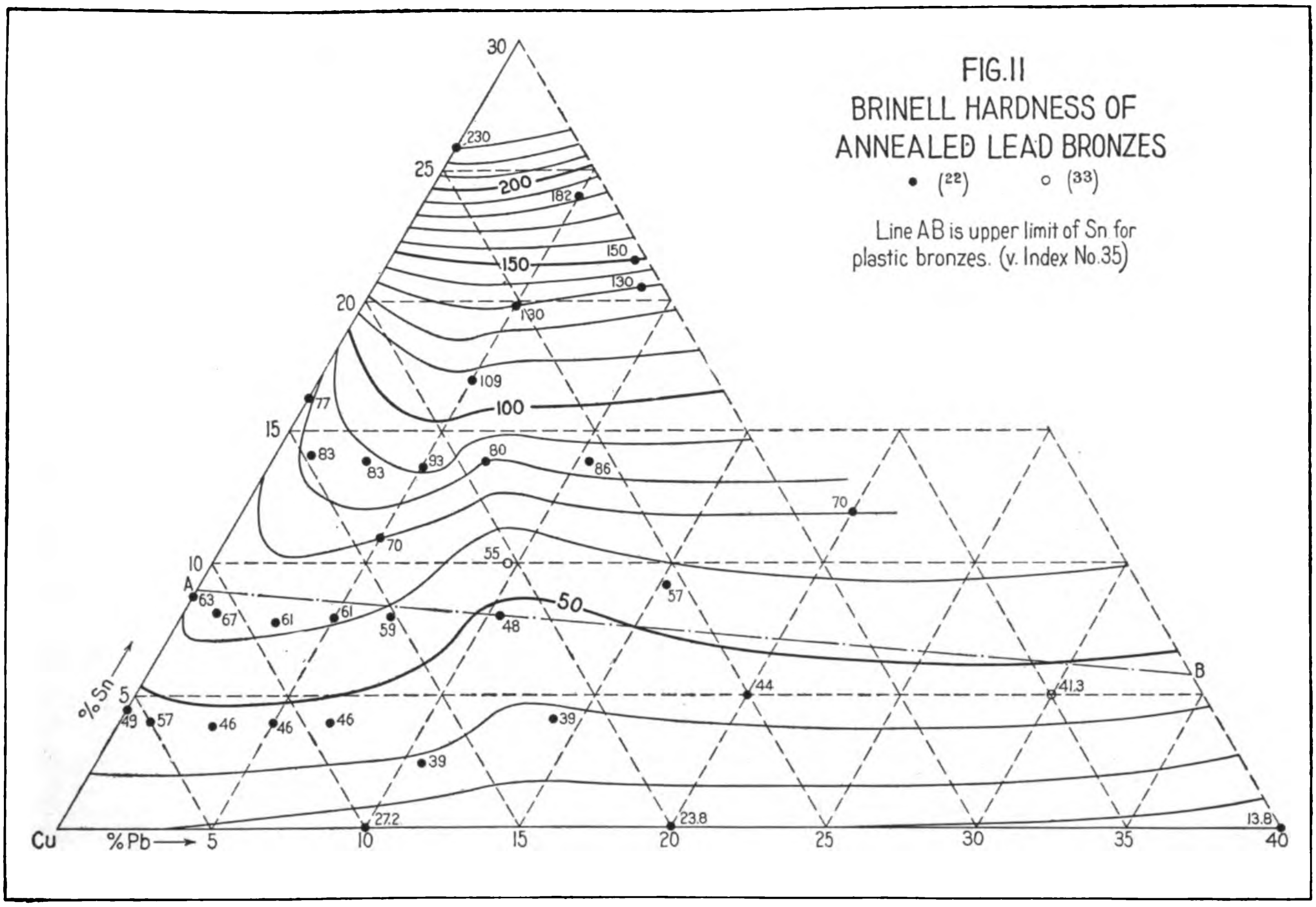


FIG. 11
BRINELL HARDNESS OF ANNEALED LEAD BRONZES
• (22) ○ (33)
Line AB is upper limit of Sn for plastic bronzes. (v. Index No. 35)
% Sn
% Pb
Cu
A
B
200
150
100
50

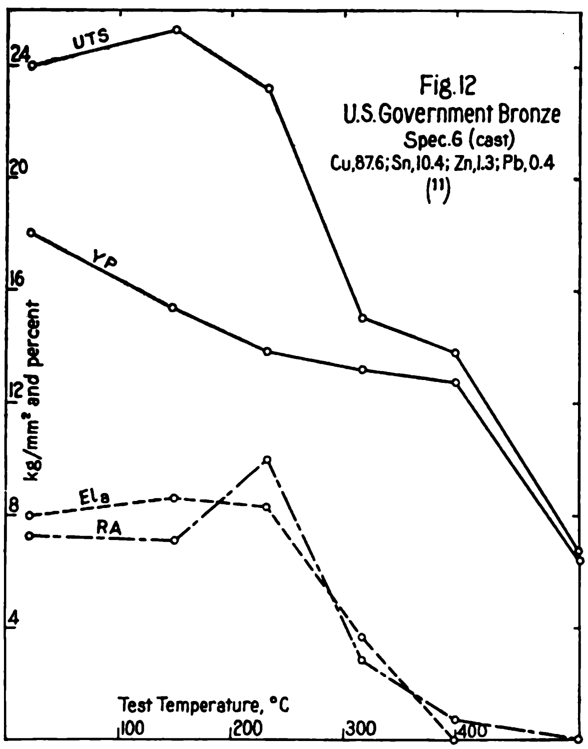


Fig. 12
U.S. Government Bronze
Spec. 6 (cast)
Cu, 87.6; Sn, 10.4; Zn, 1.3; Pb, 0.4
(11)
UTS
YP
El$_{8}$
RA
kg/mm² and percent
Test Temperature, °C

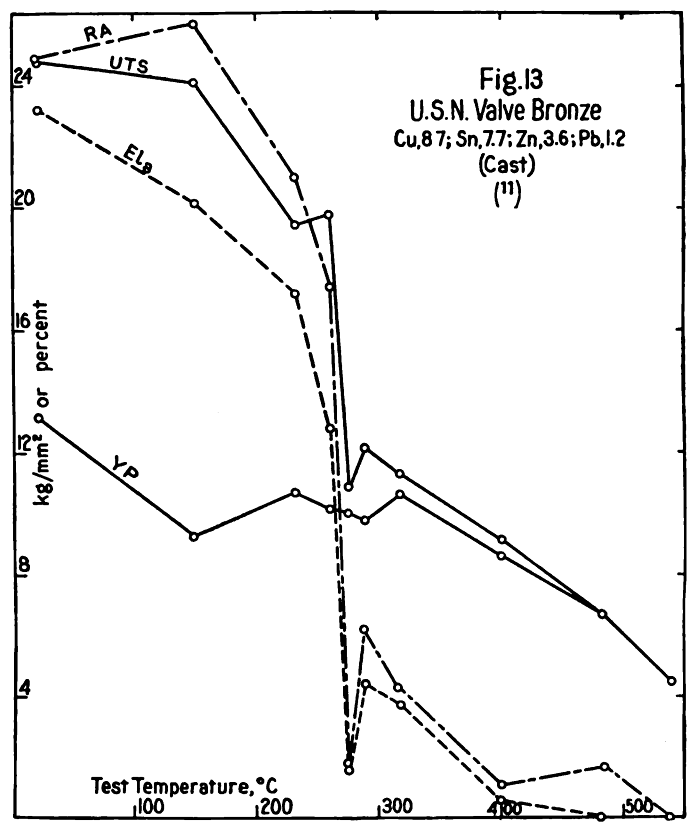


Fig. 13
U.S.N. Valve Bronze
Cu, 87; Sn, 7.7; Zn, 3.6; Pb, 1.2
(Cast)
(11)
RA
UTS
El$_{8}$
YP
kg/mm² or percent
Test Temperature, °C

Cu-Sn-Zn-Sb, Effect of Adding Sb to Admiralty Gun Metal (40)

% composition*							t_c, °C†	Trt‡	*UTS*	*YP*§	El_s ‖	*BHN*¶	*ScH***
Cu	Sn	Zn	Sb	Ni	Fe	Pb							
87.85	10.34	1.46	0.08	0.11	0.02	0.10	1240	G_s	26.9	16.4	12.8	71	15.4
							1280	G_m	23.8	16.1	2.4	81	14.8
89.44	9.55	0.55	.09	.11	.08	.11	1225	Ml_2G_s	26.0	14.6	17.0	77	14.7
							1250	Ml_2G_m	24.7	15.9	4.5	76	14.9
88.38	9.74	1.08	.50	.11	.02	.11	1220	G_s	23.9	17.3	9.2	73	15.6
							1250	G_m	23.8	16.7	2.0	82	15.5
88.38	9.73	0.93	.49	.12	.09	.07	1215	Ml_2G_s	26.0	15.1	13.8	79	15.8
							1240	Ml_2G_m	23.7	16.5	3.4	80	15.8
87.96	9.43	1.31	1.00	.10	.02	.08	1240	G_s	23.8	16.9	6.8	82	16.5
							1270	G_m	21.5	17.8	2.3	86	15.8
88.10	9.43	1.17	0.96	.10	.07	.10	1220	Ml_2G_s	21.9	14.7	6.9	81	16.5
							1245	Ml_2G_m	21.4	19.5	2.0	85	16.2
87.88	8.74	1.50	1.53	.09	.03	.07	1270	G_s	18.9	14.1	3.6	79	16.7
							1310	G_m	21.1	18.2	1.3	95	16.6
88.39	8.80	0.89	1.58	.10	.08	.07	1230	Ml_2G_s	18.3	14.9	3.8	81	16.6
							1270	Ml_2G_m	20.3	17.0	2.0	93	17.1

* All alloys contain trace of As.
† t_c = casting temperature.
‡ Bars cast 1 in. diam. × 15 in., sand cast ones being in green sand. Molds were vertical and preheated.
§ By dividers.
‖ Test piece diameter = 0.798 in. Each value mean from 2 test pieces.
¶ 10 mm, 500 kg; mean of 6 determinations.
** Each value mean of 14 determinations.

Cu-Sn-Zn-Sb, Effect of Adding Sb to 86:9:5 Red Bronze (21)

% composition*				Treatment	Part of casting	*UTS*	*El*	*BHN*†	*Tw*‡	Number of blows§
Cu	Sn	Zn	Sb							
86	9	5	0	Cast in green sand, 30 mm diam. × 160 mm long‖	Core	15.5	2.5	58	470	
					Shell	18.5	4.0			
86	9	5	0.1		Core	17.0	3.0	61	505	
					Shell	17.4	3.0			
85.25*	8.50*	5.62*	0.4*		Core	18.5	3.0	63	390	
Contains 0.2 % Pb					Shell	16.8	2.0			
86	9	5	0.5		Core	19.0	2.0	71	235	
					Shell	21.0	3.0			
86	9	5	1.0		Core	13.0	2.0	70	125	
					Shell	13.0	2.0			
86	9	5	3.0		Core	17.5	1.0	97	95	
					Shell	13 0	1.0			
86	9	5	0	Chill cast, then recast in green sand, 18 mm diam. × 180 mm long¶	Core only	24.0	7.5	65	500	230
86	9	5	0.1			25.5	7.0	73	450	325
Bal.	11.6*	4.0*	0.2*			23.3	4.5	78	540	230
Bal.	11.3*	4.5*	0.43*			24.3	7.0	74	465	470
Bal.	11.0*	4.7*	0.8*					80	280	42
86	9	5	1.0			25.3	5.5	73	340	35
86	9	5	3.0			16.5	<2	77		10
86	9	5	0	Chill cast, 18 mm diam. × 180 mm long**	Core only	20.5	4.0	81	330	3227††
86	9	5	0.1			24.5	4.5	77	350	2328††
86	9	5	0.3			20.5	2-3	75	550	830††
86	9	5	0.5				1.5	89		50††
86	9	5	1.0			22.3	2.5	84	360	60††
86	9	5	3.0			13.3		94	90	

* By analysis, other values nominal.
† 10 mm, 500 kg.
‡ Twist in degrees.
§ Energy of blow = 12.5 kg-cm.
‖ Tensile specimens 8 mm diam., torsion specimens 7 mm diam. × 140 mm long.
¶ Tensile specimens 15 mm diam., torsion specimens 15 mm diam. × 100 mm long.
** Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 120 mm long.
†† Bad break.

Cu-Sn-Zn-Pb, Effect of Adding Pb to 86:9:5 Red Bronze (20). *See also* Figs. 13 and 14

% composition				Treatment	Part of casting	*UTS*	*El*	*BHN*†	*Tw*‡	No. of blows§
Cu	Sn	Zn	Pb							
84.40*	8.63*	6.50*	0.17*	Cast in sand, 30 mm diam. × 160 mm long‖	Core	18.0	4.0	57.8	110**	
					Shell	19.6	6.0	62.7		
84.14	8.91	4.95	1.0		Core	13.8	2.7	60.5	220	
					Shell	17.0	4.0	63.0		
82.9*	8.65*	6.76*	1.71*		Core	15.2	1.5	62.5	270	
					Shell	18.0	3.0	61.5		
82.13*	8.17*	6.60*	2.84*		Core	17.0	5.2	63.0	285	
					Shell	19.2	6.5	65.5		
81.53*	8.54*	6.42*	3.52*		Core	14.2	2.2	59.0	235	
					Shell	18.0	5.0	60.5		
81.70	8.55	4.75	5.0		Core	15.0	3.0	65.0	320	
					Shell	19.5	5.2	62.0		
79.5*	8.18*	6.35*	5.89*		Core	14.3	2.0	62.5	185	
					Shell	16.8	3.3	61.5		
86	9	5	0	¶	Core only	22.0	7.8	77	200	3070
84.28	8.82	4.90	2			20.9	2.5	76	250	2380
82.56	8.64	4.80	4			14.9**	2.5	73	295	
80.84	8.46	4.70	6			13.5**	0.7	74	390	
Similar, Pb =			0.28*	Chill cast, 18 mm diam. × 160 mm long††	Core only	23.0	<3	82	260	360
			2.22*			21.5	<3	89	325	122**
			3.44*			14.3**	<3	81	285	160**
			6.23*			16.4**	<3	83	340	34**
Similar, Pb =			0.49*	Remelted and chill cast as above††	Core only	21.4	<3	83		
			2.19*			20.0	<3	80		
			3.57*			22.0	<3	84		
			6.23*			19.8	<3	82		
Similar, Pb =			0	Melted third time and chill cast as above††	Core only	23.1	<3	80		322
			2			21.4	<3	80		78**
			4			15.0**	<3	82		315
			6			17.1**	<3	81		260
Similar, Pb =			0	Chill cast, 18 mm diam. × 160 mm long‡‡	Core only	16.6	<3	87	295	53**
			2			22.8	<3	89	325	173
			4			21.8	<3	82	285	103
			6			20.0	<3	84	320	260

* By analysis, other values nominal.
† 10 mm, 500 kg.
‡ Twist in degrees.
§ Energy of blow = 12.5 kg-cm.
‖ Tensile specimens 8 mm diam., torsion specimens 8 × 5 × 40 mm.
¶ Tensile specimens 16 mm diam., torsion specimens 10 mm diam. × 80 mm long.
** Bad break.
†† Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 120 mm long.
‡‡ Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 20 mm long.

Cu-Sn-Zn-Pb-Sb, Effect of Adding Sb to Leaded 86:9:5 Red Bronze (21)

% composition*					Treatment	Part of casting	*UTS*	*El*	*BHN*†	*Tw*‡	Number of blows§
Cu	Sn	Zn	Pb	Sb							
86	9	5	2.0	0	Cast in green sand, 30 mm diam. × 160 mm long‖	Core	20.7	13	60	315	
						Shell	21.0	7.5			
86	9	5	2.0	0.1		Core	21.5	7	62	390	
						Shell	23.0	6.5			
84.55*	8.25*	4.74*	2.05*	0.4*		Core	21.5	13	70	395	
						Shell	22.5	10.5			
86	9	5	2.0	0.5		Core	17.0	2.5	65	355	
						Shell	19.3	4			
86	9	5	2.0	1.0		Core	17.5	2.5	70	270	
						Shell	19.0	4			
82.20*	8.00*	4.58*	2.08*	2.90*		Core	16.1	3.0	80	150	
						Shell	16.0	1.5			

Cu-Sn-Zn-Pb-Sb, Effect of Adding Sb to Leaded 86:9:5 Red Bronze ([21]).—(*Continued*)

% composition*					Treatment	Part of casting	*UTS*	*El*	*BHN*†	*Tw*‡	Number of blows§
Cu	Sn	Zn	Pb	Sb							
Bal.	8.7	5	2.0	0	Cast in dry sand, 18 mm diam. × 160 mm long¶	Core only	16.2	4.0	62.5	550	35–45
			2.1*	0.2*			19.0	4.0	67	620	75
			2.1*	0.4*			18.7	3.0	59	470	145–220
			2.0	0.75*			18.7	2.0	72.5	515	22
			2.0	3.0			13.5	1.0	72.5	60	1
86	9	5	5.0	0	Cast in dry sand, 18 mm diam. × 160 mm long**	Core only	21.7	7.6	65	570	383
			5.5*	0.2*			22.2	4.7	64	570	584
			5.5*	0.42*			18.4	3.5	68.5	450	163–455
			5.5*	0.74*			18.4	1.8	74	340	143
			5.0	3.0			17.6	1.8	70	195	54

* By analysis, other values nominal.
† 10 mm, 500 kg.
‡ Twist in degrees.
§ Energy of blow = 12.5 kg-cm.
‖ Tensile specimens 8 mm diam., torsion specimens 7 mm diam. × 40 mm long.
¶ Tensile specimens 15 mm diam., torsion specimens 16 mm diam. × 160 mm long.
** Tensile specimens 16 mm diam., torsion specimens 16 mm diam. × 120 mm long.

Impact Strength

% composition			Description and treatment	*IS*, kg-m	Machine	Test piece*	Lit.
Cu	Sn	Zn					
99.9			Tested at....... 20°	20.6†	Guillery	A	([24])
			−20°	18.7†			
			−80°	20.6†			
			−182°	20.1†			
99.8			Fire box plates				
			Longitudinal...........	10.4–19	Fremont	B	([9])
			Transverse.............	5.3–6.6			
84	16		A 650° or 650° Q........	†			
			Sand cast at... 1240°	2.9	Izod	C	
			1175°	3.5			
			1140°	1.95			
			≤1090°	1.2–1.4			
			Cast, tested at −80 to 375°	0.21	Charpy	D	
			470°	0.35			
94.5	4	1.5	Annealed, tested at −80°	0.7	Charpy	D	
			350–850°	0.1			
88	10	2	Casting temperature / Diameter				
			1100–1200° 0.5 in.	0.7–0.8	Izod	C	
			1.0 in.	1.4–1.5			
			1100° 2.0 in.	0.4–0.8			
			1100° 2.0 in.	1.9–2.5			
			1200° 2.0 in.	1.4–1.7			

* A = Mesnager specimen; B = bars 10 mm² cross-section, with saw cut, 3 mm deep; C = standard B. E. S. A. specimen; D = small Charpy test piece.
† Unbroken.

Specific Gravity*

% composition				Trt	d_4^{20}	Lit.
Cu	Sn	Pb	Zn			
100				D, A 500°........	8.89	([13])
99.6				G..............	8.85	([14])
				R_d, 40%........	8.89	
				A 500°..........	8.90	
90	10			G..............	8.78	([14])
80	20			G..............	8.81	([14])
70	30			G..............	8.84	([14])
95	4.9	P, 0.1		R..............	8.6	([14])
89	11	P, 0.3		G..............	8.5	([56])
80	10	10†		G..............	9.1	([14])
88	10		2	G_s..............	8.4–8.8	([29])
				G_m..............	8.6	
88	8		4	G..............	8.5	([14])
80	10		10	G_s..............	8.85	([39.1])

* *v. also* Fig. 2 and 16 and pp. 456, 554.
† Phosphor bronze.

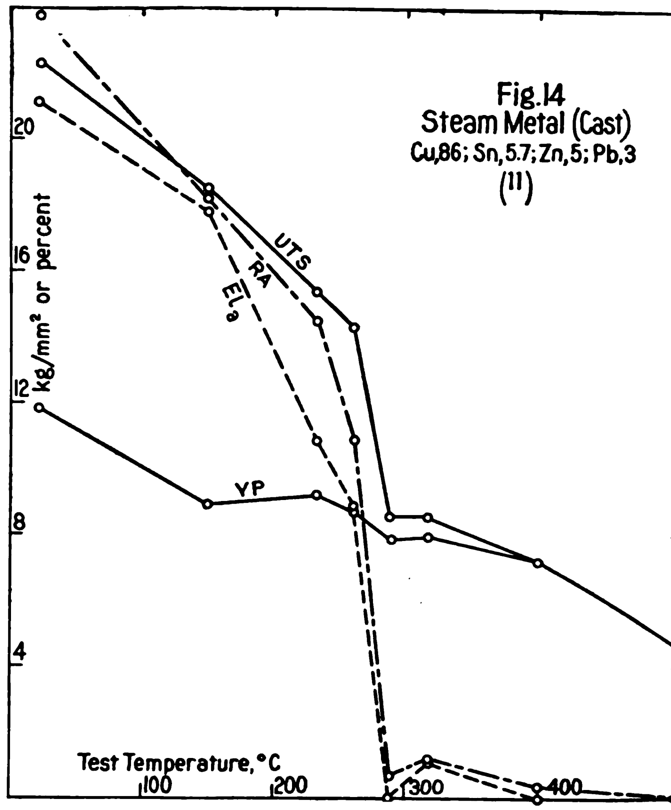


Fig. 14
Steam Metal (Cast)
Cu,86; Sn,5.7; Zn,5; Pb,3
(11)

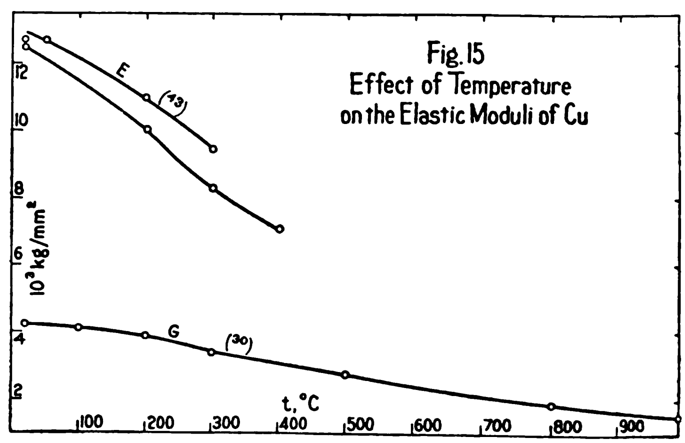


Fig. 15
Effect of Temperature
on the Elastic Moduli of Cu

Elastic Properties

See also Fig. 15

% composition				Description and treatment	$10^{-3}E$	$10^{-3}G$	$10^{-3}K$	λ	Lit.
Cu	Sn	Pb	Zn						
100 Nominal*				Electrolytic Cu	12.1–12.3				(13)
				Cast	10.85				(57)
				Drawn	12.65	3.96		0.60	(44)
				Annealed	13.19	13.2			(44)
				Hard drawn	9.8				(7)
						4.24	12.0	0.33	(30, 57)
93	7			Cast	9.8	3.7			(30, 50)
88	12			Cast	10.6	4.06			(57)
89	4	Ni, 4	3		10.5				(12)
88	5	Ni, 5	2		12.2				(12)
88	10	2		Gov. bronze specification G	8.9				(17)
				Gov. bronze specification Pc2	8.8				
86.5	10.2	0.1	3.3		9.1				(31)
85.4	12.6	0.6	1.0†		10.4				(31)

* For Cu: $E = E_0 (1 - 3.59 \times 10^{-4} t)$ at ordinary temperatures (51). $G = G_0 (1 + 2.3 \times 10^{-4} t)$ from 0 to 15° (13). $E_{0°abs}/E_{0°C} = 1.37$ (32).

† Phosphor bronze.

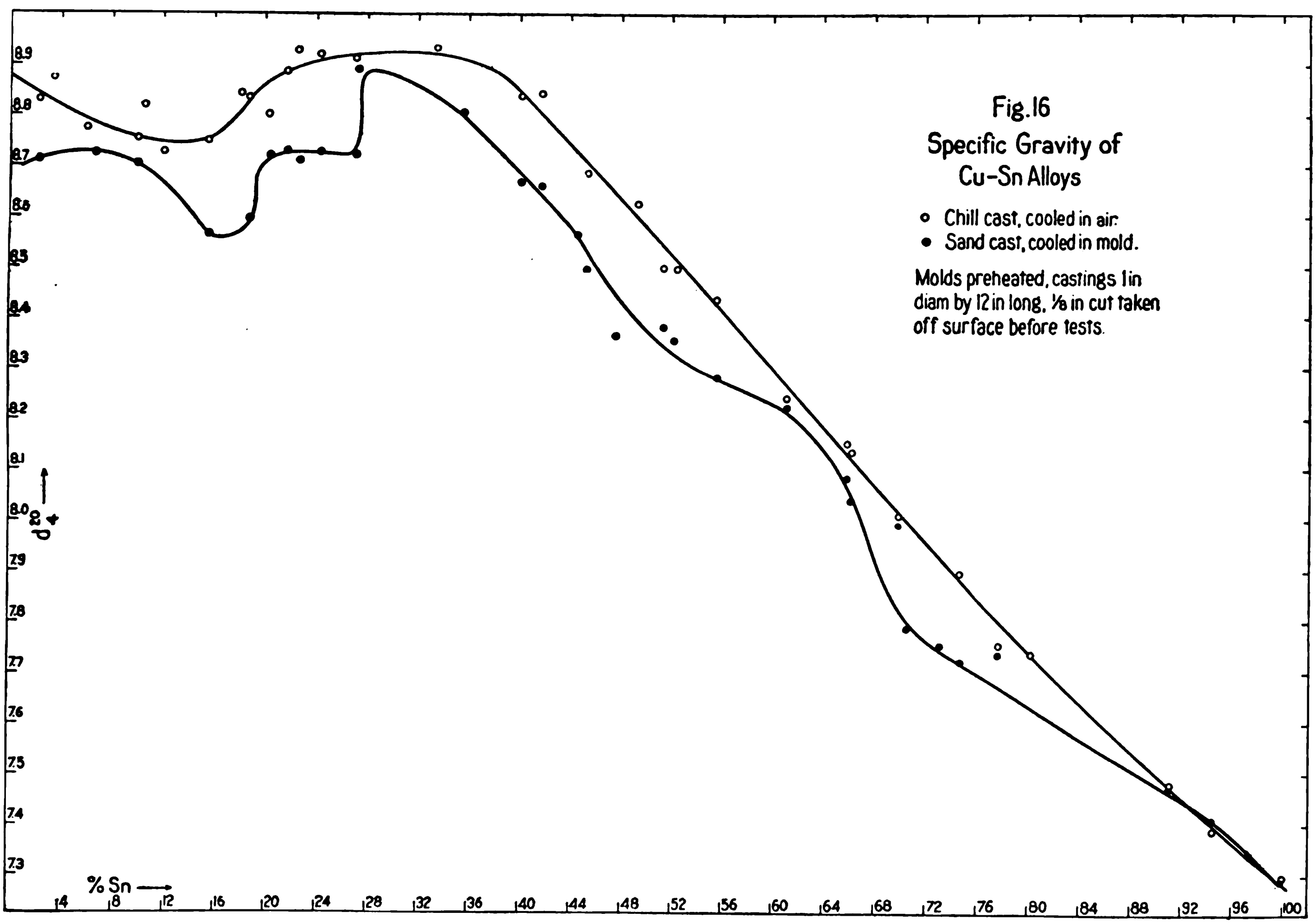


Fig. 16 Specific Gravity of Cu-Sn Alloys

Mold Shrinkage; *v. also* p. 475

% composition				Trt	$-100\frac{\Delta l}{l}$	Lit.
Cu	Sn	Pb	Zn			
94.7	5.1			G.	1.66	(58)
92	8*			G.	1.54	(37)
89.7	10.2			G.	1.44	(58)
89	11†			G.	1.04	(56)
80.7	19.1			G.	1.52	(58)
85–70	10–5	5.25		G_s.	2.08	(6)
88.8	9.7		1.6	G.	1.47	(58)
88	10		2	G.	1.50	(37)
				G_s.	1.08	(39.1)
80	10		10	G.	1.34	(37)
				G_s.	1.03	(39.1)
86.7	9.8	1.4	2	G.	1.47	(58)

* Phosphor bronze.

† Stone's English gear bronze, contains 0.3% P.

Thermal Conductivity

% composition			Treatment	t, °C	k
Cu	Sn	As			
100			Annealed (electrolytic Cu). . .	96	3.77
				625	3.52
99.6		0.39	Annealed.	90	2.14
				420	2.22
88	12		As cast (phosphor bronze). . . .	94.5	0.539
		Zn		431	0.728
88	10	2	As cast (Gov. bronze).	83.5	0.573
				418.5	0.720
86	9	5	As cast.	88	0.715
				418.5	0.808

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(For a key to the periodicals see end of volume)

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PROPERTIES OF ALUMINUM BRONZES

W. M. Corse

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Cu-Al

PROPERTIES OF Cu-Al, Al > 15%

The alloys of this series between 15 and 90% Al do not appear to be of any technical value. From 15 to 18% Al they are very hard and very brittle. From 20 to 65% Al they diminish in hardness, but are so brittle they can be powdered easily in a mortar, which makes them of some use in weighing out quantities to make up alloys. This excessive brittleness ceases at about 67% Al (3).

TABLE 1.—AVERAGE PROPERTIES (13)

% Cu	% Al	Treatment	*UTS*	*YP*	*El*	*RA*	*BHN*	d_4^{20}
95	5	R_d sheet.....	70		10			8.18
		R_a sheet......	39		75			
92	8	R_d sheet.....	91		4			7.80
		R_a sheet......	42		60			
90	10	G_s...........	46–53	14–21	20	21	90–100	DL_C = 13–14
		Wk_d rod.....	88		5			
		Wk_a rod.....	55		36			

Table 2.—Tensile Properties* (Al < 14%) (3).—(*Continued*)

Treatment†	10 × *UTS*	10 × *YP*‡	El_s§	*RA*
Cu, 99.86; Al, 0.10; Si, 0.000; Fe, 0.000				
G_s	181	60	46.0	
G_s, W 800° C_s	179	66	40.0	
G_s, W 900° Q_w	168	46	40.0	
G_m	182	65	46.0	
G_m, W 800° C_s	174	77	44.0	
G_m, W 800° Q_w	178	63	47.5	
R_h $\frac{13}{16}$ in. diam.	228	109	65.5	90.7
Same, W 800° C_s	223	69	62.0	92.5
Same, W 800° Q_w	221	69	65.0	91.8
Cu, 98.95; Al, 1.06; Si, 0.010; Fe(Tr.)				
G_s	211	47	52.0	
G_s, W 800° C_s	203	50	46.0	
G_m	186	82	53.0	
G_m, W 800° C_s	203	71	57.0	
G_m, W 800° Q_w	199		53.5	
R_h $1\frac{1}{4}$ in. diam.	247	106	59.0	90.9
R_h $\frac{13}{16}$ in. diam.	250	109	61.0	88.6
Same, W 800° C_s	240	69	67.0	91.9
Same, W 800° Q_w	243	68	63.5	90.8
D_c $\frac{13}{16}$ in. diam.	285	273	42.0	88.8
Cu, 97.88; Al, 2.10; Si, 0.018; Fe, 0.004				
G_s	213	54	53.5	
G_s, W 800° C_s	221	55	46.5	
G_s, W 800° Q_w	221	68	47.0	
G_m	216	71	54.5	
G_m, W 800° C_s	219	76	56.0	
G_m, W 800° Q_w	219	68	55.0	
R_h $1\frac{1}{4}$ in. diam.	271	101	61.0	90.0
R_h $\frac{13}{16}$ in. diam.	275	136	56.5	89.7
Same, W 800° C_s	262	69	66.0	90.0
Same, W 800° Q_w	264	68	63.5	88.8
Cu, 96.98; Al, 2.99; Si, 0.024; Fe, 0.008				
G_s	229	60	60.0	
G_s, W 800° C_s	233	58	60.5	
G_s, W 800° Q_w	233	77	58.5	
G_m	217	107	60.0	
G_m, W 800° C_s	230	69	73.0	
G_m, W 800° Q_w	235	74	53.0	
R_h $1\frac{1}{4}$ in. diam.	299	124	67.0	88.8
R_h $\frac{13}{16}$ in. diam.	312	183	57.3	86.1
Same, W 800° C_s	284	76	73.0	90.0
Same, W 800° Q_w	285	87	69.0	88.8
Same, W 600° C_f	292	109	66.0	89.8
Same, W 900° C_f	311	91	82.5	83.6
D_c $\frac{13}{16}$ in. diam.	351	331	44.0	86.1
Cu, 95.92; Al, 4.05; Si, 0.019; Fe, 0.011				
G_s	263	55	83.0	
G_s, W 800° C_s	268	62	68.5	
G_s, W 800° Q_w	260	79	60.0	
G_m	269	77	82.0	
G_m, W 800° C_s	258	68	89.0	
G_m, W 800° Q_w	279	80	81.0	
R_h $1\frac{1}{4}$ in. diam.	346	115	71.0	81.8
R_h $\frac{13}{16}$ in. diam.	375	178	67.0	83.3
Same, W 800° C_s	339	96	73.0	85.7
Same, W 800° Q_w	335	101	79.0	84.8

Table 2.—Tensile Properties* (Al < 14%) (3).—(*Continued*)

Treatment†	10 × *UTS*	10 × *YP*‡	El_s§	*RA*
Cu, 94.90; Al, 5.07; Si, 0.018; Fe, 0.006				
G_s	285	68	75.0	
G_s, W 800° C_s	296	57	65.5	
G_s, W 800° Q_w	293	79	66.5	
G_m	285	112	60.5	
G_m, W 800° C_s	284	80	61.0	
G_m, W 800° Q_w	301	90	80.0	
R_h $1\frac{1}{4}$ in. diam.	387	107	79.0	77.0
R_h $\frac{13}{16}$ in. diam.	416	180	69.2	77.8
Same, W 800° C_s	373	82	79.0	82.0
Same, W 800° Q_w	371	98	83.0	78.8
D_c $\frac{13}{16}$ in. diam.	479	375		
Cu, 94.20; Al, 5.76; Si, 0.027; Fe, 0.010				
G_s	280	76	67.0	
G_s, W 800° C_s	306	60	65.0	
G_s, W 800° Q_w	285	85	52.5	
G_m	296	95	61.0	
G_m, W 800° C_s	307	88	74.0	
G_m, W 800° Q_w	323	129	49.0	
R_h $\frac{13}{16}$ in. diam.	448	186	74.2	76.9
Same, W 800° C_s	419	124	77.5	71.0
Same, W 800° Q_w	393	109	84.5	75.6
Same, W 600° C_f	429	148	77.0	75.0
Same, W 900° C_f	373	95	86.0	70.0
Cu, 93.23; Al, 6.73; Si, 0.026; Fe, 0.016				
G_s	294	76		
G_s, W 800° C_s	297	76	64.0	
G_s, W 800° Q_w	313	99	51.0	
G_m	315		69.0	
G_m, W 800° Q_w	298	82	42.0	
R_h $1\frac{1}{4}$ in. diam.	412	118	82.0	75.4
R_h $\frac{13}{16}$ in. diam.	455	164	71.0	75.0
Same, W 800° C_s	418	112	82.5	73.5
Same, W 800° Q_w	401	117	83.0	72.0
Cu, 92.61; Al, 7.35; Si, 0.027; Fe, 0.017				
G_s	336	104	71.0	
G_s, W 800° C_s	317	93	81.0	
G_s, W 800° Q_w	315	106	70.0	
G_m	340		84.0	
G_m, W 800° C_s	318	95	80.0	
G_m, W 800° Q_w	312	115	79.0	
R_h $1\frac{1}{4}$ in. diam.	432	147	80.0	75.3
R_h $\frac{13}{16}$ in. diam.	468	167	72.5	74.3
Same, W 800° C_s	401	117	80.5	74.8
Same, W 800° Q_w	402	126	82.0	74.8
Same, W 900° C_f	376	112	92.0	72.0
D_c $\frac{13}{16}$ in. diam.	495	388	48.0	58.8
Cu, 91.85; Al, 8.12; Si, 0.012; Fe, 0.012				
G_s	393	121	58.0	
G_s, W 800° C_s	349	109	60.0	
G_s, W 800° Q_w	410	124	62.5	
G_m	433	153	62.0	
G_m, W 800° C_s	350	115	59.0	[illegible]
G_m, W 800° Q_w	393	132	61.0	[illegible]
R_h $1\frac{1}{4}$ in. diam.	487	154	[illegible]	[illegible]
R_h $\frac{13}{16}$ in. diam.	524	205	[illegible]	[illegible]
Same, W 800° C_s	430	128	[illegible]	[illegible]
Same, W 800° Q_w	448	118	[illegible]	[illegible]

TABLE 2.—TENSILE PROPERTIES* (AL < 14%) (3).—(*Continued*)

Treatment†	10 × *UTS*	10 × *YP*‡	El_a§	*RA*
Cu, 91.28; Al, 8.67; Si, 0.032; Fe, 0.021				
G_s	443	154	48.0	
G_s, W 800° C_s	370	139	48.0	
G_s, W 800° Q_w	484	184	35.0	
G_m	485		55.0	
G_m, W 800° C_s	427	139	63.0	
G_m, W 800° Q_w	470	153	54.0	
R_h 13/16 in. diam.	578	175	38.0	50.7
Same, W 800° C_s	473	180	65.0	64.9
Same, W 600° Q_w	596		48.0	61.2
Same, W 700° Q_w	554		54.0	66.7
Same, W 800° Q_w	551	199	51.0	59.6
Same, W 900° Q_w	618		40.0	51.7
Cu, 90.58; Al, 9.38; Si, 0.021; Fe, 0.019				
G_s	479	153	36.3	47.2
G_s, W 900° C_s	369	169	17.3	31.9
G_s, W 800° Q_w	601	328	9.5	20.0
G_m	536	165	43.5	50.0
G_m, W 800° C_s	433	178	27.0	30.5
G_m, W 800° Q_w	561	295	28.0	46.3
R_h 1¼ in. diam.	589	233	40.0	41.4
R_h 13/16 in. diam.	599	279	34.0	33.6
Same, W 600° Q_w	614	251	38.5	50.8
Same, W 700° Q_w	607	262	35.5	42.9
Same, W 800° Q_w	615	301	32.0	42.7
Same, W 900° Q_w	668	292	25.5	39.3
D_c 13/16 in. diam.	612	457	32.0	46.3
Cu, 90.06; Al, 9.90; Si, 0.027; Fe, 0.017				
G_s	499	178	21.7	
G_s, W 800° C_s		210	‖	
G_s, W 800° Q_w	788	353	3.0	
G_m	582	195	30.5	
G_m, W 800° C_s	416	260	5.0	
G_m, W 700° Q_w	601	200	25.0	32.0
G_m, W 800° Q_w	607	217	22.0	28.5
	608	279	22.0	
G_m, W 900° Q_w	709	577	3.0	10.8
R_h 1¼ in. diam.	552	214	31.5	30.5
R_h 13/16 in. diam.	600	233	28.8	30.8
Same, W 800° C_s	449	247	6.5	10.2
Same, W 300° C_f	600	230	27.0	33.1
Same, W 400° C_f	499	369	2.5	2.9
Same, W 500° C_f	537	323	9.5	13.1
Same, W 600° C_f	500	247	9.0	14.5
Same, W 700° C_f	502	238	9.0	11.3
Same, W 800° C_f	413	200	13.5	21.6
Same, W 900° C_f	346	210	6.0	8.8
Same, W 600° Q_w	608	268	29.0	35.7
Same, W 700° Q_w	585	246	20.5	27.0
Same, W 800° Q_w	717	413	11.0	16.8
Same, W 900° Q_w	854	659	2.5	7.0
R_h¶, W 600° Q_w	602	268	22.2	30.0
R_h¶, W 700° Q_w	626	285	15.4	20.6
R_h¶, W 800° Q_w	686	511	7.0	14.3
R_h¶, W 900° Q_w	812	627	3.0	4.8
D_c 13/16 in. diam.	692	637	13.0	22.2

TABLE 2.—TENSILE PROPERTIES* (AL < 14%) (3).—(*Continued*)

Treatment†	10 × *UTS*	10 × *YP*‡	El_a§	*RA*
Cu, 89.17; Al, 10.78; Si, 0.031; Fe, 0.015				
G_s	465	222	9.0	
G_s, W 800° C_s	460	425	2.0	
G_s, W 800° Q_w	559	468	2.5	
G_m	579	266	9.0	
G_m, W 800° C_s	453	372	0.0	
G_m, W 800° Q_w	510	421	3.0	
R_h 1¼ in. diam.	551	284	12.5	12.1
R_h 13/16 in. diam.	609	243	14.0	18.6
Same, W 800° C_s	479	291	1.5	4.0
Same, W 800° Q_w	569	189	5.0	13.3
Cu, 88.32; Al, 11.73; Si, 0.028; Fe, 0.010				
G_s	401	221	5.0	
G_s, W 800° C_s	305	305	1.0	
G_s, W 800° Q_w	391	265	5.0	
G_m	482	233	6.0	
G_m, W 800° Q_w	395	197	5.0	
R_h 1¼ in. diam.	506	299	5.5	4.2
R_h 13/16 in. diam.	533	199	8.5	15.4
Same, W 800° C_s	385		1.0	2.7
Same, W 800° Q_w	401	189	6.0	10.6
Cu, 86.92; Al, 13.02; Si, 0.043; Fe, 0.013				
G_s	311	311	1.0	
G_s, W 800° C_s	249	249	2.0	
G_s, W 800° Q_w	365	220	4.5	
G_m	395	395	0.0	
G_m, W 800° C_s	260	260	0.0	
G_m, W 800° Q_w	409	186	4.0	
R_h 13/16 in. diam.	585		2.0	1.9

* The alloys in this table were made up of 99.98–99.99 % pure Cu and 99.70 % pure Al. A specimen of 99.96 % pure Cu, R_h to 13/16 in. and C_s from 800°C had the following properties: *UTS* = 22.3, *YP* = 7.9, *El* = 56.0, *RA* = 67.8. The ductility is greatly increased by adding only 0.1 % Al. Additional properties of the commercially important Al bronzes are given in the following tables.

† Treatments in detail are: G_s, in small test piece size; G_m, in 1 in. diam. size and machined down. The mechanically worked specimens are from a G_m 20 × 3 in. diam. ingot. This was machined to 2 13/16 in. diam., W 800° R to 1¼ in. diam. One portion R_h to 13/16 in. diam.

‡ By dividers.

§ Test piece 0.564 in. diam., 2 in. gage length except where noted.

‖ Broke in threads, fracture coarsely crystalline.

¶ These specimens were machined to test piece size (½ in. diam.) before heat treatment.

TABLE 3.—TENSILE PROPERTIES AT HIGH TEMPERATURES

t,°C	Cu, 95; Al, 5 Cast (2, 15)				Cu, 90; Al, 10 Cast (2, 15)		
	UTS	*YP*	El_a	*RA*	*UTS*	El_a	*RA*
20	24.7	19.5	56.3	46.9	29.1	9.4	13.1
150	22.7		78.1	31.4			
230	25.2	11.0	65.7	61.7	29.7	12.5	4.8
315	17.3	12.9	45.3	38.4	27.0	11.5	11.6
400	4.5	4.5	0.0	0.0	18.8	1.6	2.9
510					18.2	3.1	6.7
540	4.4	4.4	0.0	0.0			

TABLE 3.—TENSILE PROPERTIES AT HIGH TEMPERATURES.—(*Continued*)

t,°C	Cu, 93; Al, 6.7 (R_h)* ([23]; *cf.* [27])		Cu, 90; Al, 10 (R_h)* ([23]; *cf.* [27])	
	UTS†	El_a	*UTS*†	El_a
20	45.5	71.0	60.0	28.8
200			57.4	35.0–38.0
250	37.3	25.5–29.0	50.0	21.5
300	32.6	24.5–25.0	52.6	18.5–40.0
350	30.3	17.5	51.7	27.5–33.0
400	28.2	14.0–18.0	37.8	29.0–48.0
450	21.0	9.0–10.0	35.1	30.5–32.5
500	17.2	14.0	19.1	42.0–92.5
550			14.3	10.2

* For exact composition v. Table 2. Specimens hot rolled to 13/16 in. diam.
† Mean values.

TABLE 4.—BRINELL HARDNESS AT HIGH TEMPERATURES ([12])

% Al	Impurities \ t,°C	20	250	350	450	550	650	750	850	950
3.82	Si, 0.09.....	39.4	33.8	31.4	31.4	31.4	22.4	17.6	13.2	
4.07	Si, 0.08.....	38.1	29.6	28.4	29.2	29	27.4	17.2		
6.75	Sn, 0.27.....	34.9	34.4	31.4	31.4	31.8	29.7	16.5	8.2	
9.76	Fe, 0.22....	76.7	71.1	65.1	61	40.5	25.4	14.2	7	2.9

TABLE 5.—BRINELL HARDNESS ([3])

% Al	Trt* \ Load, kg	1034	3000	*UTS*
0.10	R_h..................	78	66	22.8
2.99	R_h..................	109	102	31.2
5.07	R_h..................	113	124	41.6
7.35	R_h..................	123	134	46.8
9.90	R_h..................	180	210	60.0
11.73	R_h..................	213	269	53.3
13.02	R_h..................	332	349	58.5
13.50	G_s..................	372	437	
15.38	G_s..................	411	539	

* Tests, except last two, made on 13/16 in. diam. hot rolled bars. Ball diam. = 9.516 mm.

TABLE 6.—TORSIONAL STRENGTH* ([3])

% Al	*USS*c	*TMR*	*UTS*	Twist, °/cm
0.00	19.8	26.4		359
0.10	25.2	33.7	22.4	681
1.06	26.0	34.7	24.7	570
2.10	27.2	36.3	27.1	506
4.05	31.0	41.4	34.6	304
6.73	36.4	48.6	41.2	213
7.35	37.2	49.6	43.2	180
9.90	36.8	49.3	55.2	31
11.73	39.5	52.7	50.6	6.7

* Specimens machined from 1¼ in. bar, hot rolled to 0.624 in. diam. × 3.0 in. long, except for 2.1 % Al which is 2.8 in. long.

TABLE 7.—DYNAMIC TESTS ([3])

% Al	No. of bends*		*IS*† (Izod)	Condition after Izod test
	⅝ in. diam.	⅝ in. sq.		
0.10	287	443	1.23	Unbroken
2.99	332	456	1.70	
5.07	632	814	1.96	
7.35	1395	1373	2.13	

TABLE 7.—DYNAMIC TESTS ([3]).—(*Continued*)

% Al	No. of bends*		*IS*† (Izod)	Condition after Izod test
	⅝ in. diam.	⅝ in. sq.		
9.90	657	783	0.62	Broken
11.73			0.54	
13.02			0.12	

* Tests made on Arnold machine, bars 5.5 in. long.
† Tests bars 2 × ⅜ × 5/16 in. For both tests, bars were machined from hot rolled 13/16 in. diam. bars.

TABLE 8.—SPECIFIC GRAVITY OF AL-BRONZES ([3])

% Al \ Trt	G_s	G_m	R*
0.10	8.90	8.90	8.92
1.06	8.79	8.77	8.78
2.10	8.54	8.61	8.62
2.99	8.44	8.47	8.47
4.05	8.29	8.31	8.31
5.07	8.16	8.18	8.18
5.76	8.04	8.07	8.07
6.73	7.94	7.96	7.95
7.35	7.85	7.86	7.85
8.12	7.79	7.78	7.78
8.67	7.73	7.69	7.69
9.38	7.64	7.61	7.61
9.90	7.60	7.56	7.56
10.78	7.45	7.45	7.45
11.73	7.19	7.34	7.35
13.02	6.98	7.23	7.23

* Rolled to 13/16 in. diam.

TABLE 9.—COMPRESSIBILITY AND SPECIFIC GRAVITY OF CU-AL ALLOYS ([14])

% Al *ca.*	t,°C	$10^6 \chi$*	t,°C	d_4*
5	16	103	17.4	8.16
7	15	119	14.7	7.95
13	20.5	81	20.4	7.29
20	19	118	19	5.61
43	19	160	18.2	4.40
50	20.5	250	23	4.06
63	26	231	25.2	3.57
90	26	210	25.2	2.83

* Average between 1 and 1000 atm.

TABLE 10.—SPECIFIC GRAVITY ([1])

% Al	d_4^{20}	% Al	d_4^{20}	% Al	d_4^{20}
0	8.92	15.0	6.93	64	3.68
7	7.83	22.5	6.08	82	3.09
12.5	7.30	35	4.88	100	2.69
14.7	6.97	46	4.26		

TABLE 11.—EFFECT OF COLD ROLLING AND ANNEALING ON MECHANICAL PROPERTIES OF CU, 92.99; AL, 7.03 ([17])

Treatment (rolled plate)	*UTS*		*El**		*BHN*‡
	L†	T†	L†	T†	
R_h 16 mm, R_c 8 mm........	74.0	74.4	10	9	183
R_h 20 mm, R_c 8 mm........	79.6	80.2	9	4	205
R_h R_c A 500°.............	50.5	50.6	46	111	111
R_h R_c A 600°.............	46.0	54.7	57	75	75

* On 50 mm.
† L, T specimens taken parallel and perpendicular to direction of rolling, respectively.
‡ 10 mm ball, 500 kg load.

TABLE 11.—EFFECT OF COLD ROLLING AND ANNEALING ON MECHANICAL PROPERTIES OF Cu, 92.99; Al, 7.03 (17).—(*Continued*)

Ann. temp., °C	*UTS**	*El**	Ann. temp., °C	*UTS**	*El**
(R_h)	75.8	8	305	79.0	6
100	76.3	7	335	76.9	6
155	77.2	8	360	67.4	13
180	77.2	7	385	62.7	17
210	78.6	6	410	55.4	30
230	79.7	6	460	52.3	40
260	79.7	6	510	51.1	40
285	79.7	5			

* R_h 16 mm, R_c 8 mm (‖).

Ann. temp., °C	*BHN*†	Ann. temp., °C	*BHN*†
(R_h)	205	290	222
70	204	315	218
120	206	340	192
170	209	365	152
195	210	390	138
215	209	415	123
240	216	465	114
265	217	515	111

† R_h 20 mm, R_c 8 mm (‖).

TABLE 12.—EFFECT OF HEAT TREATMENT ON ROLLED Cu, 90; Al, 10* (19)

Treatment	*UTS*	*YP*	*El*†	*BHN*	*ScH*‡	*IS*§
R A 750°/90	49		14	125¶	19.2	3.5**
R W 500° 5 m‖ Q_w	48		13	125¶	18	3.2**
R W 600° 5 m‖ Q_w	61		20.5	121¶	27	7**
R W 700° 5 m‖ Q_w	60	.	22	122¶	26.5	8**
R W 800° 5 m‖ Q_w	72		9	148¶	46.7	6.1**
R 800°/10 Q_w‖	69.2	23.3	8	184††	49	6.2‡‡
Same, W 10 m 400°	73.9	23.4	2.5	205††	55	3.8‡‡
Same, W 10 m 500°	62	29.5	12	162††	42.5	4.6‡‡
Same, W 10 m 600°	59.2	22.3	21.7	144††	38	8.6‡‡
Same, W 10 m 700°	51.2		13.5	120††	32	10.5‡‡
R 900°/20 Q_w	67.7	39.7	3.5	223††	44	4‡‡
Same, W 10 m 400°	64.1	45.5	2.2	208††	69.7	5.7‡‡
Same, W 10 m 500°	60.6	34.4	12.0	152††	46	8.6‡‡
Same, W 10 m 600°	60.7	27.7	26.5	133††	41.6	12.5‡‡
Same, W 10 m 700°	57.6	29	22.7	129††	40.1	14.4‡‡

* Cu, 89.84; Al, 9.95; Zn, 0.11; (Si, Fe), Tr.
† Test pieces 10 mm square cross-section.
‡ Hardened steel point.
§ Guillery machine.
‖ Heated in salt bath.
¶ 10 mm, 1000 kg.
** Copenhagen test piece.
†† 10 mm, 2000 kg.
‡‡ Mesnager test piece.

TABLE 13.—EFFECT OF HEAT TREATMENT ON CAST Cu, 90; Al, 10 (7, 26)

t,°C	Trt A* *BHN*	Trt B* *BHN*	*t*,°C	Trt A* *BHN*	Trt B* *BHN*
(G_s)	118		705	133	115
370		230	760	163	110
425	121	178	815	205	108
480		157	870	240	
540	128	140	925	240	
595	112	133	980	200	
650	121	125			

* Trt A = Wt° Q_w; Trt B = W 870° Q_w Tp t°; *BHN*: 10 mm, 1000 kg.

TABLE 13.—EFFECT OF HEAT TREATMENT ON CAST Cu, 90; Al, 10 (7, 26).—(*Continued*)

Treatment	*UTS*	*EL*	*El*
G_s	42.2	10.5	28.5
800° Q_w	68.9	21.8	8.0
900° Q_w	66.8	38.7	3.5
Same, Tp 500°	60.5	34.4	12.0
Same, Tp 705°	56.2	28.8	22.7

Treatment	*UTS*	*EL*	*El*$_s$	*RA*	*BHN*
G_s	52.0	13.9	19.5	23.7	100
900° Q_w	74.0	28.5	1.0	0.8	262
Same, Trt	68–64	40–27.5	5.5–14	9–18.5	158–140

TABLE 14.—EFFECT OF HEAT TREATMENT ON HARDNESS OF CAST Cu, 90; Al, 10* (6)

Tempering temp., °C	*ScH*		*BHN*† (heat A), at:			*BHN*† (heat H), at:		
	Heat A	Heat H	3000 kg	1000 kg	500 kg	3000 kg	1000 kg	500 kg
None	43–54	46–55	248	249	206	248	244	
150	48–55	56–58	241	249		235	238	
205	50–55	52–56	241	238		241	249	
260	53–57	53–58	262	260		255	249	
315	46–53	57–61	262	260		269	260	
400	49–60	56–62	262	260		269	260	
480	30–32	34–36	170	165		179	171	
565	23–27	23–26	163	159	136		159	143
650	21–22	22–24		133	124		138	130
760	19–20	19–20		121	100		121	109
870	18–19	20–21	131	113	100	134	117	109

* Disks ¼ in. thick cut from tensile test stubs of cast alloy having: *UTS* = 45–53; *YP* = 15–18; *El* = 17–23 %; *RA* = 16–26 %. Stubs W 900°/20–30 Q_w Tp t° C_{CaO}.
† 10 mm ball.

Tempering temp., °C*	*ScH*†		*BHN* (3000 kg)	
	Heat A	Heat F	Heat A‡	Heat F†
None	55–59	58–61	255	269
150	54–57	55–59	248	277
205	54–57	56–61	241	269
260	55–58	59–61	269	277
315	52–55	57–61	262	286
345	54–57	58–62	262	286
370	48–52	55–58	277	286
400	48–50	50–53	269	269
425	36–39	42–44	196	255
455	25–27	38–42	183	223
480	21–24	29–31	179	202
510	20–22	26–28	170	196

Tempering temp., °C	Air cooled§		Cooled in CaO§	
	ScH	*BHN*‖	*ScH*	*BHN*‖
None	60–65		59–66	
150	62–66	249		
205			61–63	260
230	62–67	260		
260			60–63	244
315	62–66	285	65–70	278
345	63–70	279	60–64	272
370	60–66	255		
400	59–62	255		
425	48–55	205		

* Same treatment as above except where air cooled.
† On flattened surface of edge of disks ¼ in. thick.
‡ On faces of same disks.
§ On flats filed on tensile test stubs.
‖ Load = 1000 kg.

TABLE 15.—EFFECT OF HEAT TREATMENT ON HARDNESS AND ENDURANCE TO REVERSED BENDING OF CAST CU, 90; AL, 10 (22)

Cu, 90.5; Al, 9.5

Quench temp., °C*	900	800	700	600	500	400	300	200	Room
No. bends†		230	400	1340	1200	850	500	600	200
BHN (10 mm, 500 kg)	86	89	80	74	67	65	66	63	70

* 900° C_s W t° Q_w. † Arnold machine.

Cu, 90; Al, 10

Treatment	No. bends	*BHN*
G	650	
G, A 300°	600	
G, A 400°	550	
G, A 500°	130	
G, A 650°	630	
G, A 800°	1050	
900° Q_w	5	130
Same, A 400°	7	123
Same, A 500°	50	119
Same, A 600°	300	100
900° Q_w A 700°	500	93
900° Q_w A 800°	470	80
800° Q_w	2	
Same, A 400°	2	143
Same, A 500°	10	100
Same, A 600°	270	80
Same, A 700°	355	86
700° Q_w	6	100
Same, A 400°	150	93
Same, A 500°		86
Same, A 600°	400	74
600° Q_w	400	86
Same, A 400°	300	80
Same, A 500°	84	86
500° Q_w	40	84
Same, A 400°	20	86

Cu-Al-Fe

TABLE 16.—AVERAGE PROPERTIES (13)

% Al	% Fe	Treatment	*UTS*	*YP*	*El*	*RA*	DL_C	*BHN*
10	1	G_s	46–53	14–21	24	27	13–14	92–96
10	3	Wk_d rod	91		5			
		Wk_a rod	63		30			
9	3	G_s	46–56	25–32	20–40	20–40	10–13	95–120
8	3	Wk_d rod	88		5			
		Wk_a rod	51		50			

U. S. master specification (No. 173) for Al-bronze ingots: Cu, 85–89; Al, 7.0–9.0; Fe, 2.5–4.5; Sn, <0.5; other elements, <0.25. *UTS* ≮ 52.7 kg/mm²; *YP* ≮ 21.1 kg/mm²; El_a ≮ 30%.

Proposed U. S. master specification for Al-bronze castings: Desired: Cu, 88; Al, 9.0; Fe, 3.0; Sn, 0; other elements, 0. Permissible: Composition, *UTS*, and El_a as for ingots.

TABLE 17.—TENSILE PROPERTIES AND HARDNESS OF SAND CAST ALLOYS* (10)

% Al	% Fe	*UTS*	*YP*†	*PL*	El_a	*RA*	*BHN*‡
7	1	37.4	11.0	10.1	56.0	54.2	70
	2	44.3	13.3	12.2	39.0	35.6	70
	3	52.4	16.4	15.0	38.0	32.2	80
	4	53.7	16.6	15.5	38.5	35.7	89
	5	51.7	17.4	15.2	29.0	26.9	
	6	54.5	17.8	15.1	31.5	27.6	
	8	52.4	18.0	16.6	27.5	27.6	
8	1	40.1	13.7	11.5	45.0	43.4	70
	2	44.8	14.5	12.8	39.0	39.2	80
	3	57.0	18.3	17.0	36.5	32.9	109
	4	57.7	18.5	17.4	35.0	32.0	109
9	1	48.8	16.4	13.0	43.0	35.7	77
	2	55.0	18.1	15.7	30.5	27.4	109
	3	57.4	19.9	18.0	26.0	26.9	109
	4	58.3	20.0	18.6	23.0	23.8	109
10	1	54.1	16.9	13.9	24.5	25.2	94
	2	58.1	18.8	16.0	21.0	19.2	100
	3	60.7	20.2	18.3	20.0	20.5	109
	4	62.3	21.1	19.3	17.0	18.5	119
	5	56.6	23.2	20.7	12.5	16.9	
	6	60.1	23.5	21.8	13.0	14.7	
	8	60.8	25.2	22.4	11.5	12.4	

* All specimens ½ in. diam., sand cast.
† By dividers.
‡ 10 mm ball, 500 kg load applied 30 sec.

TABLE 18.—PROPERTIES OF LARGE AND SMALL CASTINGS (8)

v. also Table 21

Treatment and description	*UTS*	*YP*	*El*	*RA*
Cu, 89.0–89.5; Al, 9.5–10.0; Fe, 1.0				
G (semi-chill) 1.25 in. diam.	53.4–55.5	13.4–14.1*	28–30	27–31
Large gear	45.1	18.1	12.0	14.7
Small bars cast with large	37.9–49.2	17.6–21.1	10–20	12–23
Machined from same large casting	36.5–40.1	16.2–18.3	12–14	14–20
G ½ in. sq. unmachined	53.1	14.5	24	22.4
G ½ in. diam. unmachined (av.)	54.1	16.9	24.5	25.2
Cu, 88; Al, 9; Fe 3				
	49.2	21.1	20	

* *PL*.

TABLE 19.—TENSILE PROPERTIES AND YOUNG'S MODULUS (5)

Treatment and test method*	*UTS*	*YP*	*PL*	*EL*	El_a	*RA*	10^{-3} *E*
Cu, 89; Al, 10; Fe, 1							
G_s, method A	51.2	18.8	8.9	7.9	22.0	22.7	
G_s, method B	51.1		9.1		29.0	26.1	102
G_s, method C	51.6	18.7	7.7	6.0	20.5	21.6	109
G_s, Trt, method A	65.2	40.3	21.8	18.3	12.6	14.8	
G_s, Trt, method C	57.5	36.3	23.9	21.1	9.0	16.5	105
Cu, 86; Al, 10; Fe, 4							
G_s, method A	56.7	22.6	12.4	11.2	18.0	18.6	
G_s, method B	49.9		14.4		9.0	10.4	112
G_s, Trt, method A	70.3	41.8	25.4	20.5	16.0	17.2	

* Method A: Berry strain gage used for *E*, *EL*, *PL* and *YP*, in one position only. Method B: Mean of three strain gage readings taken, gages 120° apart. Method C: Special extensometer giving mean of strains on opposite sides used.

TABLE 20.—BRINELL HARDNESS NUMBER* AT HIGH TEMPERATURES (12)

No. \ t,°C	20	250	350	450	550	600	650	700	800	900	950
1†	125	84.5	82.5	80	69.8	54		34.5	20	11.5	10.5
2†	131.5	125.2	117.5	96.6	79.6		14.5	9.8			

* 10 mm, 500 kg.
† No. 1: Al, 7.64; Fe, 2.12; Mn, 0.49. No. 2: Al, 10.55; Fe, 4.22; Mn, 0.74.

TABLE 21.—EFFECT OF HEAT TREATMENT ON SAND CAST ALLOYS* (4, 9)

Treatment	Size†	*UTS*	*PL*	*El*	*RA*	*BHN*‡
G_s	A	52.0	13.9	19.5	23.7	100
600° Q_w	A	55.9	10.8	21.0	22.2	
850° Q_w§	A	68.4	28.0	1.0	0.0	240
850° C_a 10s Q_w	A	73.9	28.5	1.0	0.8	262‖
850° C_a 20s Q_w	A	64.3	23.3	2.0	5.7	229‖
850° C_a 30s Q_w	A	51.4	16.6	5.0	9.4	150
850° C_a 45s Q_w	A	50.9	11.0	7.0	12.2	
850° Q_w, W 650°/15 C_a	A	60.9	24.7	13.0	14.9	130
850° Q_w, W 650°/15 C_f	A	66.0	30.2	12.5	12.3	143
850° Q_w, W 500°/30 C_f	A	67.5	39.8	5.5	9.1	158
850° Q_w, W 575°/20 C_f	A	66.1	32.4	8.0	11.2	143
850° Q_w, W 610°/15 C_f	A	68.0	30.4	10.5	12.6	140
850° Q_w, W 650°/15 C_f	A	64.1	27.6	14.0	18.5	143
850° Q_w, W 700°/15 C_f to 550°, C_a	A	56.2	16.4	23.0	21.7	104
G_s	B	40.3	12.7	12.5	15.0	
850° Q_w, W 600° C_f	D	65.6	37.7	10.0	13.5	
850° Q_w, W 630° C_f	D	62.2	30.4	13.0	14.2	
850° Q_w, W 650° C_f	C	52.0	24.3	14.5	17.6	
850° Q_w, W 650° C_f	B	59.8	28.7	12.5	15.7	
850° Q_w, W 650° C_f	B	55.0	27.9	9.5	15.0	
850° Q_w, W 650° C_f	B	52.5	28.3¶	9.0	13.5	
G_s A	B	38.8	16.0	9.0	11.2	109

* Cu, 88.63; Al, 10.67; Fe, 0.91.
† A = cast to size 0.493–0.521 in. diam., 2 in. gage length. B = Trt in 2 × 4 × 9 in. block size. C = Trt in 2¼ in. diam. size. D = Trt in 1½ in. diam. size.
‡ 10 mm, 500 kg except those marked ‖.
‖ 10 mm, 3000 kg.
§ Adopted as proper quenching temperature.
¶ This value is a *YP*.

Cu-Al-Mn

TABLE 22.—TENSILE PROPERTIES* (25)

v. also Table 26

Treatment†	10 × *UTS*	10 × *YP*‡	El_a	*RA*
Cu, 89.54; Al, 10.03; Mn, 0.43				
G_s	517	225	24	
G_m	567	251	24	
R_h 1¼ in. diam.	635	294	24.5	
R_h $\frac{13}{16}$ in. diam.	621	309	31	29.2
D_c $\frac{13}{16}$ in. diam.	728	662	13	18.8
Cu, 89.10; Al, 9.89; Mn, 1.01 and (Cu, 89.06; Al, 10.02; Mn, 0.92)§				
G_s‖	563	221	22.5	
A 550°/1 h	446	200	15.0	
A 800°/1 h	459	208	17.0	
550°/1 h Q_w	501	214	18.5	
800°/1 h Q_w	650	205	6.0	
800°/15 Q_w	599	208	7	
G_m‖	629	252	25.0	
R_h 1¼ in. diam.‖	600	270	26.5	32.4
R_h $\frac{13}{16}$ in. diam.	658	291	30	
R_h $\frac{13}{16}$ in. diam.‖	675	363	22.5	33.6
A 550°/1 h	589	340	5.0	
A 800°/1 h	545	241	31.0	
A 900°/6 h	501	203	29	
550°/1 h Q_w	621	321	16.0	
880°/1 h Q_w	717	381	11.5	
D_c $\frac{13}{16}$ in. diam.‖	788	662	16.0	
Cu, 88.00; Al, 9.99; Mn, 2.01 and (Cu, 88.30; Al, 9.82; Mn, 1.88)§				
G_s	542	208	24	
A 550°/1 h	507	173	15	
A 850°/1 h	630	205	12	
550°/1 h Q_w	534	195	11	
850°/1 h Q_w	647	284	5	
850°/15 Q_w	646	208	7	
G_m	583	265	25	
R_h 1¼ in. diam.	637	287	35.0	31.3
R_h $\frac{13}{16}$ in. diam.‖	659	284	24	
R_h $\frac{13}{16}$ in. diam.	642	337	29.0	32.0
A 550°/1 h	614	350	7.5	
A 850°/1 h	559	230	26.5	
A 900°/6 h	536	195	24	
550°/1 h Q_w	662	301	25.0	
850°/1 h Q_w	819	397	3.5	
D_c $\frac{13}{16}$ in. diam.	820	644	10.0	
Cu, 89.91; Al, 9.16; Mn, 0.93				
G_s	484	176	46.5¶	
G_m	534	205	46.0	
R_h 1¼ in. diam.	572	257	45.0	46.0
R_h $\frac{13}{16}$ in. diam.	603	335	41.5	54.0
Cu, 88.99; Al, 9.06; Mn, 1.95				
G_s	494	167	40.0¶	
G_m	523	223	30.0	
R_h 1¼ in. diam.	585	265	43.5	47.2
R_h $\frac{13}{16}$ in. diam.	613	321	42.0	48.0
D_c $\frac{13}{16}$ in. diam.	667	581	23.5	40.8
Cu, 88.06; Al, 9.10; Mn, 2.84 and (Cu, 88.11; Al, 8.91; Mn, 2.98)§				
G_s‖	498	170	24**	
A 550°/1 h	492	204	35	
A 900°/1 h	426	164	49	
550°/1 h Q_w	501	227	31.5	
900°/1 h Q_w	620	271	9	
900°/15 Q_w	567	249	11.5	
G_m‖	542	233	26	
R_h 1¼ in. diam.‖	609	284	43.5	46.0
R_h $\frac{13}{16}$ in. diam.‖	630	315	39.0	43.6
R_h	649	303	40.0	
A 550°/1 h	646	350	27.0	
A 900°/1 h	501	199	43.0	
A 900°/6 h	487	196	37.5	
550°/1 h Q_w	492	320	39.0	
900°/1 h Q_w	689	314	23.0	
D_c $\frac{13}{16}$ in. diam.	693	613	22.0	40.0
Cu, 86.89; Al, 9.33; Mn, 3.78				
G_s	506	193	20.0	
G_m	624	238	32.0	
R_h 1¼ in. diam.	601	265	34.0	38.4
R_h $\frac{13}{16}$ in. diam.	639	286	35.0	38.0
D_c $\frac{13}{16}$ in. diam.	689	641	21.0	34.0

TABLE 22.—TENSILE PROPERTIES* [25].—(*Continued*)

Treatment†	10 × *UTS*	10 × *YP*‡	El_a	*RA*
Cu, 88.04; Al, 8.02; Mn, 3.94				
G_s	454	180¶	31.5	
G_m	521	208	50.0	
R_h 1¼ in. diam	561	257	49.0	56.0
R_h 13/16 in. diam	590	295	45.0	54.0
D_c 13/16 in. diam	624	549	35.0	55.2
Cu, 87.16; Al, 7.92; Mn, 4.92				
G_s	441	177	30.0	
G_m	479	195	28.0	
R_h 1¼ in. diam	571	277	52.0	54.8
R_h 13/16 in. diam	577	304	45.0	51.2
D_c 13/16 in. diam	649	548	30.0	49.2

* Alloys contained small amounts of Fe and Si which should be deducted from figures for Al; amounts are given for only three alloys in original paper.

† For more detailed statement of treatments *v.* footnote to Table 2. There was no material difference between G_s to shape and G_s machined.

‡ By dividers.

§ Tests on alloy in parentheses, are indicated by ‖ in column 1 of this section.

¶ Discrepancy between two tests of *ca.* 13 %.

** Broke outside gage marks.

TABLE 23.—TENSILE PROPERTIES AT HIGH TEMPERATURES [25]

t,°C*	*UTS*	*YP*	El_a
	Al, 9.89; Mn, 1.01		
200	62.4	24.1	36.5
250	62.2	29.6	43.0
300	57.3	30.7	47.0
350	51.9	30.6	40.0
400	35.8	21.8	57.0
450	27.2	18.4	51.0
	Al, 9.99; Mn, 2.01		
200	62.3	30.3	28.0
250	61.6	31.6	35.0
300	58.3	26.3	45.0
350	49.3	26.8	45.0
400	31.8	22.1	41.5
450	22.0	15.6	35.5
	Al, 9.10; Mn, 2.84		
200	62.4	29.8	40.5
250	62.0	32.8	47.0
300	56.1	31.0	37.0
350	46.8	29.3	36.0
400	32.2	21.3	39.5
450	20.4	14.4	56.0
500	14.5		38.0

* Held at this temperature 30 min before testing.

TABLE 24.—HARDNESS AND TORSIONAL STRENGTH OF HOT ROLLED ALLOYS* [5]

% Al	% Mn	*BHN*† (A)	*BHN*† (B)	*ScH*	*UTS*	USS_C	*TMR*	Twist, °/cm
10.03	0.43	170	199	27	63.5	35.7	47.6	26.3
10.02	0.92	158	190	27	60.0	34.6	46.2	26.6
9.82	1.88	164	193	27	63.7	37.6	50.2	35.8
9.16	0.93	146	171	23	57.2	34.6	46.2	40.3
9.06	1.95	165	184	24	58.5	37.5	50.1	46.3
8.91	2.98	158	187	25	60.9	37.5	50.1	43.9
9.33	3.78	165	186	25	60.1	35.7	47.6	33.4
8.02	3.94	159	170	22	56.1	37.5	50.1	66.6
7.92	4.92	149	169	22	57.1	38.5	51.4	72.4

* From 1¼ in. diam. bars, torsion pieces 3 × 0.624 in. diam.

† A = 1034 kg, B = 3000 kg, ball diam. = 9.52 mm.

TABLE 25.—DYNAMIC STRESS TESTS ON HOT ROLLED ALLOYS* [25]

Reversed bend test

% Al	% Mn	No. bends†
10.03	0.43	877
10.02	0.92	1104
9.82	1.88	933
9.16	0.93	741
9.06	1.95	738
8.91	2.98	680
9.33	3.78	694
8.02	3.94	441
7.92	4.92	423

Single blow impact			Impact bending test		
% Al	% Mn	*IS*‡ (Izod)	Wt. of Tup, kg	Ht. of Fall, cm	No. blows§
10.02	0.92	1.37	2.79	5.11	918
			2.14	2.57	10 006
9.82	1.88	1.37	2.79	5.11	762
			2.14	2.57	12 713
8.91	2.98	1.44	2.79	5.11	600
			2.14	2.57	11 396

* Test pieces taken from hot rolled bars 1 3/16 in. diam. For fatigue endurance limits *v. p.* 595.

† Test piece ⅜ in. diam., Arnold machine.

‡ Notched specimen 2 × ⅜ × 3/16 in.

§ Test piece ½ in. diam., V notch, bottom diam. = 0.4 in., Bairstow machine.

TABLE 26.—ELASTIC PROPERTIES* [25]

% Al	% Mn	10^{-3} *E*	*PL*
R_h, to 1 3/16 in. diam.			
10.02	0.92	9.56	12.8
9.82	1.88	9.77	14.5
8.91	2.98	10.47	19.2
D_c, to 1 3/16 in. diam.			
9.89	1.01	9.49	19.4
9.99	2.01	9.28	19.4
8.91	2.98	10.40	24.1

* By Ewing extensometer.

TABLE 27.—SPECIFIC GRAVITY (d_4^{20}) [25]

% Al	Trt / % Mn	G_s	G_m	R_h	D_c
10.03	0.43	7.62	7.55	7.54	
10.02	0.92	7.53	7.51	7.52	7.56
9.82	1.88	7.62	7.51	7.53	7.52
9.16	0.93	7.64	7.55	7.61	
9.06	1.85	7.57	7.63	7.60	
8.91	2.98	7.57	7.57	7.59	7.59
9.33	3.78	7.52	7.63	7.56	
8.02	3.94	7.64	7.73	7.67	
7.92	4.92	7.65	7.76	7.63	7.60

TABLE 28.—EFFECT OF ANNEALING ON PROPERTIES OF COLD ROLLED SHEET [24]

% Al	% Mn	Trt*	*UTS*	*YP*	*El*†	*BHN*‡
2	5	R	47.1	46.6	9	145
		A	35.3	16.4	45	83
3	0	R	42.2	41.9	9	137.5
		A	27.9	9.1	55	60
3	1	R	42.2	41.3	11.5	141.5
		A	31.8	15.8	50	72.5
3	3	R	43.6	43.0	12	140
		A	33.7	16.1	48	78.5

TABLE 28.—EFFECT OF ANNEALING ON PROPERTIES OF COLD ROLLED SHEET ([24]).—(*Continued*)

% Al	% Mn	Trt*	*UTS*	*YP*	*El*†	*BHN*‡
4	5	R	56.2	55.1	15.5	182
		A	42.1	17.8	55	95
5	0	R	55.3	54.0	16.5	174.5
		A	40.2	13.1	70	84.5
5	1	R	49.0	45.2	27	162.5
		A	41.4	18.9	57	89.5
6	3	R	61.4	60.2	12	
		A	46.9	21.6	58	
7	0	R	62.7	61.0	17.5	195
		A	43.3	11.0	71	75.5
7	1	R	55.9	53.7	28	184
		A	46.1	18.1	65	99.5

* R = G_{phm} R_h (1.5–⅜ in.) $P_w R_c$ 0.14 in. A = A 650°/30 C_a.
† On 2⅜ in.
‡ 5 mm, 300 kg.

TABLE 29.—EFFECT OF ANNEALING ON SCLEROSCOPE HARDNESS OF COLD DRAWN BARS* ([22])

% Al	% Mn \ Ann. *t*, °C	20	250	400	550	700	900
10.02	0.92	34.5	34.5	34.5	25	20	16
9.82	1.88	34	33.5	33	25	19	18
8.91	2.98	29	29	29	21.5	16	15

* Specimens exposed 30 min to each temperature in succession.

TABLE 30.—EFFECT OF HEAT TREATMENT ON PROPERTIES OF ROLLED CU, 88.80; AL, 10.02; MN, 1.11; ZN, 0.05; (SI, FE), TR. ([19])

Treatment	*UTS*	*YP*	*El*$_1$*	*BHN*	*ScH*†	*IS*‡
R A	48.5		13	120§	37.2	3.6¶
R W 500° 5 m Q_w	47.1		11	122§	38	2.5¶
R W 600° 5 m Q_w	57		13	128§	35	6.8¶
R W 700° 5 m Q_w	59		16	123§	28	8¶
R W 800° 5 m Q_w	64.2		2.2	187§	53	5¶
R 800°/10 Q_w	68.7	23.9	2.2	222‖	58.2	5**
Same, W 10 m 400°	80.1	23.3	1	231‖	69.5	3.8**
Same, W 10 m 500°	61.1	24	12	162‖	41.7	6.2**
Same, W 10 m 600°	61.4	22.5	31.7	138‖	35.0	15.6**
Same, W 10 m 700°	48.4	21.5	32	124‖	35.2	16.8**
R 900°/20 Q_w	66.1		0	203‖	40.2	9.7**
Same, W 10 m 400°	65.8	42	1	228‖	84.6	4**
Same, W 10 m 500°	59.1	32.3	12	167‖	49.5	9.7**
Same, W 10 m 600°	62.6	29	21.2	140‖	45	14.9**
Same, W 10 m 700°	60	27	25.1	128‖	39.4	17.7**

* Test pieces 10 mm square.
† Hardened steel point.
‡ Guillery machine.
§ 10 mm, 1000 kg.
‖ 10 mm, 2000 kg.
¶ Copenhagen test piece.
** Mesnager test piece.

Cu-Al-Ni

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI ([21])

Treatment	*UTS*	*YP*	*PL*	*El*$_a$*	*RA*	*BHN*	*ScH*	d_4^{20}	No. bends†
Cu, 94.98; Al, 5.02 and (Cu, 94.88; Al, 5.12)‡									
G_m	29.5§	7.9§		68.0§	58.2§	58	9.0		
R A 900°‖	34.9	8.2		82.5	78.9	61	8.5	8.18	741
R, W 900° Q_w¶	35.9	10.1**		78.6	73.3	52††	11.0	8.18	1045
R_c	42.8	27.4		64.0	75.1	114	17.0	8.17	773

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI ([21]).—(*Continued*)

Treatment	*UTS*	*YP*	*PL*	*El*$_a$*	*RA*	*BHN*	*ScH*	d_4^{20}	No. bends†
Cu, 93.96; Al, 5.10; Ni, 0.94 and (Cu, 93.94; Al, 5.06; Ni, 1.00)‡									
G_m	30.3§	8.7§		92.1§	69.1§	59	10.5		
R A 900°‖	35.9	8.3		94.6	76.1	64	10.5		746
R, W 900° Q_w¶	36.0	10.4**		85.6	73.8	56††	11.0		862
R_c	44.4	28.5		63.1	78.1	113	18.5		580
Cu, 92.68; Al, 4.94; Ni, 2.38									
G_m						59	11.0	8.14	
R A 900°‖	36.0	8.7		90.2	71.0	66	11.0	8.17	671
R, W 900° Q_w¶	39.1	11.3		77.8	71.4	62††	11.5	8.16	738
R_c	47.4	35.4		55.0	66.7	124	210	8.16	354
Cu, 89.84; Al, 5.32; Ni, 4.84 and (Cu, 90.04; Al, 4.91; Ni, 5.05)‡									
G_m	29.4§	8.8§		86.5§	73.4§	60	12.0	8.15	
R A 900°‖	40.3	14.8		70.0	60.2	80	12.5	8.18	445
R, W 900° C_a	37.5	12.0		81.0	68.7				
R A 900°	44.2	16.5	9.5	56	52				
R, W 900° Q_w¶	38.1	11.9		86.8	72.4				
	38.0	12.0**	6.3	85	71	61††	12.0	8.18	400
R_c	49.0	37.0		50.0	72.3	136	23.0	8.17	229
Cu, 87.48; Al, 5.21; Ni, 7.31 and (Cu, 87.30; Al, 5.39; Ni, 7.31)‡									
G_m	32.2§	11.7§		79§	59§	77	13.5	8.15	
G_m A 900°‡‡	52.5§	35.9§		10.5§	19§	171§			
R A 900°‖	61.4	37.8		25.6	26.8	167	27.0	8.19	193
R, W 900° C_a	42.6	18.3		63.9	69.9				
R A 900°‡‡	64.5	39.4	25.2	17	21				
R, W 900° Q_w	46.9	17.9**		52.1	65.1				
	43.2	12.9	6.3	63	69	92††	17.0	8.18	258
R_c	57.2	49.0		28.8	41.0	156	27.5	8.18	150
Cu, 87.32; Al, 5.34; Ni, 7.34									
R_c ½ in. diam.	84.1	81.1	9.5	12	38				
A 100°/30 m	79.1	77.7	14.2	12	43				
A 200°/30 m	76.4	74.8	23.6	13	41				
A 300° 30 m	75.0	72.9	42.5	12	48				
A 300° 68 h	73.1	69.0	45.7	24	58				
A 420°/30 m	70.6	67.4	50.4	20	47				
A 500° 15 m	76.9	72.9	58.3	21	45				
A 500° 30 m	77.3	73.2	52.0	17	41				
A 500° 1 h	80.2	76.4	55.1	21	49				
A 500° 4 h	79.7	69.6	47.3	21	36				
A 500° 6 h	78.6	67.7	36.2	21	35				
A 600° 30 m	68.8	55.6	37.8	23	38				
A 700° 30 m	61.9	46.5	31.5	34	51				
A 800° 30 m	52.5	26.5	23.6	50	64				
R ⅞ in. diam. Q_w	41.0	12.6	6.3	72	69				
R ⅞ in. diam. C_a‡‡	65.1	39.4	26.8	22	23				
R ½ in. diam. Q_w	45.2	13.9	6.3	68	70				
R ½ in. diam. C_a§§	60.3	30.7	18.9	28	32				
900° Q_w (½ in. diam.)	45.2	13.9	6.3	68	70				
Same, Tp C_a 600°/30	61.2	36.5	25.2	17	25				
Same, Tp C_a 600°/2 h	64.2	40.9	28.4	13	20				
Same, Tp C_a 700°/30 h	65.3	35.4	23.6	28	32				
Same, Tp C_a 800°/30	51.6	20.3	13.4	44	43				
Same, Tp C_a 815°/30	46.8	15.1	9.5	67	67				
R_c ⅞ in. diam.	61.5	57.9	28.3	20	43	177			
R_h ½ in. diam.	69.3	63.5	47.3	20	52	235			
R_c ½ in. diam.	84.1	81.1	9.5	12	38	234			
Cu, 85.03; Al, 5.55; Ni, 9.42									
G_m	44.5	23.6		39.7	39.0	115	17.0	8.13	
Cu, 79.90; Al, 5.20; Ni, 14.90									
G_m	65.4	55.3		4.7	10.0	173	37.0	8.14	
Cu, 87.16; Al, 6.62; Ni, 6.22									
G_m	32.0	10.1		77	70	69			
G_m A 900° C_a‡‡	50.6	25.2		19.5	25	147			
G_m, W 900° Q_w Tp‖‖	48.2	29.8		8.5	17				
Cu, 87.45; Al, 6.93; Ni, 5.62									
R_c ½ in. diam.	89.0	87.2	18.9	9	32				
A 100° 30	85.2	82.8	22.1	12	38				
A 200° 30	84.3	83.1	31.5	9	38				
A 300° 30	83.3	82.2	53.6	12	43				
A 300°/68 h	82.7	80.0	56.7	14	47				

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI (21).—(Continued)

Treatment	UTS	YP	PL	El*	RA	BHN	ScH	d_4^{20}	No. bends†
Cu, 87.45; Al, 6.93 Ni, 5.62.—(*Continued.*)									
A 420° 30	81.0	78.9	48.9	14	47				
A 500° 30	83.8	79.5	39.4	17	38				
A 600° 30	70.9	57.3	25.2	28	40				
A 700° 30	63.6	44.1	23.6	33	53				
A 800° 30	59.4	32.4	23.6	47	60				
R ¾ in. diam. Q_w	42.6	13.2	7.1	80.5	75				
R ¾ in. diam. C_a‡‡	59.1	28.4	16.5	29.5	35				
R ½ in. diam. Q_w	46.0	13.6	6.3	73	69				
R ½ in. diam. C_a§§	60.5	25.7	16.5	36	34				
900° Q_w (½ in. diam.)	46.0	13.6	6.3	73	69				
Same, Tp C_a 600°/30	62.5	29.0	18.9	34	32				
Same, Tp C_a 600°/2 h	65.2	35.4	22.8	22	20				
Same, Tp C_a 700°/30	68.1	35.8	20.5	26	25				
Same, Tp C_a 700°/30	61.0	24.3	15.8	36	33				
R_c ¾ in. diam.	60.0	54.5	20.5	27	47	176			
R_h ½ in. diam.	77.3	72.6	47.3	20	47	241			
R_c ½ in. diam.	89.0	87.2	18.9	9	32	237			
R_c ¾ in. diam., W 300° C_a	59.7	53.2	36.2	22	51				
Cu, 87.58; Al, 7.39; Ni, 5.03									
G_m	34.8	12.9		50	56	84			
G_m A 900° C_a‡‡	47.6	20.8		24.5	34	132			
G_m, W 900° Q_w Tp‖‖	48.8	30.2		8	15				
Cu, 85.18; Al, 7.88; Ni, 6.94									
G_m	40.1	15.1		69	56	87			
G_m A 900° C_a‡‡	52.9	26.2		17.5	28	150			
G_m, W 900° Q_w Tp‖‖	49.3	36.9		4	9				
Cu, 87.45; Al, 7.91; Ni, 4.64									
R_c ½ in. diam.	85.2	82.7	9.5	15	36				
A 100° 30	84.3	81.1	14.2	12	36				
A 200° 30	88.7	86.6	15.8	9	29				
A 300° 30	88.5	87.6	42.5	9	35				
A 300°/68 h	88.4	87.4	47.3	14	38				
A 420° 30	85.4	84.3	52.0	13	38				
A 500° 30	83.2	80.0	48.8	15	38				
A 600° 30	70.6	55.5	33.1	29	47				
A 700° 30	67.2	42.7	31.5	39	47				
A 800° 30	64.1	35.5	29.9	46	47				
R ¾ in. diam. Q_w	42.5	13.9	7.1	75	70				
R ¾ in. diam. C_a‡‡	56.3	22.7	13.4	33	37				
R ½ in. diam. Q_w	47.7	14.3	7.1	74	59				
R ½ in. diam. C_a§§	59.6	22.7	12.6	37	38				
900° Q_w (½ in. diam.)	47.7	14.3	7.1	74	59				
Same, Tp C_a 600°/30	62.2	26.2	15.8	36	34				
Same, Tp C_a 600°/2 h	63.8	31.5	17.3	26	22				
Same, Tp C_a 700°/30	67.4	31.8	17.3	24	25				
Same, Tp C_a 800°/30	62.5	25.0	12.6	30	31				
R_c ¾ in. diam.	64.0	58.4	25.2	23	42	189			
R_h ½ in. diam.	78.8	73.2	50.4	22	47	231			
R_c ½ in. diam.	85.2	82.7	9.5	15	36	249			
Cu, 89.94; Al, 10.06 and (Cu, 90.00; Al, 10.00)‡									
G_m	47.9§	18.3§		19.4§	27.2§	135	20.0	7.54	
R A 900°‖	40.5	22.7		9.0	10.4	127	20.5	7.54	38
R, W 900° Q_w¶	84.3	55.1**		2.3	3.9	257	62.0	7.54	
R_c	69.8	66.1		9.0	12.4	186	33.0		231
Cu, 89.14; Al, 9.82; Ni, 1.04 and (Cu, 89.48; Al, 9.56; Ni, 0.96)‡									
G_m	55.9§	20.2§		20.2§	21.5§	150	33.0		
R A 900°‖						139	22.0		
R, W 900° Q_w¶						211	56.0		
R_c						214	39.0		
Cu, 87.66; Al, 9.88; Ni, 2.46									
G_m						176	36.5	7.55	
R A 900°‖	50.2	28.5		12.3	13.0	158	27.0	7.54	57
R 900° Q_w¶	71.4			5.4	5.4	206	49.0	7.54	
R_c	80.8	58.1		13.0	11.0	207	38.0	7.56	165
Cu, 85.11; Al, 9.94; Ni, 4.95 and (Cu, 85.26; Al, 9.56; Ni, 5.18)‡									
G_m	62.6§	31.3§		7.2§	10.1§	199	41.0	7.56	
R A 900°‖	54.5	28.4		16.2	17.4	151	25.0	7.63	147
R, W 900° C_a	65.7	28.5		12.9	10.0				
R, W 900° Q_w¶	73.3	28.4**		4.2	5.5	251	53.0	7.63	
R_c	81.0	63.3		12.1	8.4	216	40.0	7.63	145

TABLE 31.—PROPERTIES OF ALLOYS CONTAINING UP TO 10% AL, 15% NI (21).—(Continued)

Treatment	UTS	YP	PL	El*	RA	BHN	ScH	d_4^{20}	No. bends†
Cu, 82.82; Al, 9.70; Ni, 7.48									
G_m						179	35.0	7.60	
R A 900°‖	61.3	29.6		13.1	15.1	162	26.0	7.57	54
R, W 900° C_a	67.2	26.8		15.2	14.1				
R, W 900° Q_w¶	78.1	31.5**		6.3	5.5	209	40.0	7.58	
R_c	82.0	75.3		12.3	16.3	231	43.0	7.57	54
Cu, 79.94; Al, 9.92; Ni, 10.14 and (Cu, 80.39; Al, 9.61; Ni, 10.00)‡									
G_m	60.6	39.5		2.8	4.6	182	35.0	7.53	
G_m A‖	58.6§	30.4§		15.0§	17.8§				
R A 900°						173	28.0		
R, W 900° Q_w¶						214	45.0		
Cu, 75.34; Al, 10.04; Ni, 14.62 and (Cu, 74.26; Al, 9.99; Ni, 15.75)‡									
G_m	46.0	26.0		3.2	5.5	182§	32.0§	7.60	
R, W 900° Q_w¶						205§	45.0§		

* Diam. = 0.564 in.
† No. of bends, Arnold machine.
‡ Data for the alloy in parentheses are marked § in this section.
‖ A 900°/15 C_f, (900–450°/90 m).
¶ Trt 1 in. diam. W 900°/15 Q_w.
** By extensometer, all others by autographic recorder.
†† Load = 1000 kg.
‡‡ C 900–700°/35 m.
§§ C 900–700°/200 m.
‖‖ Tp 700°/30 C_a.

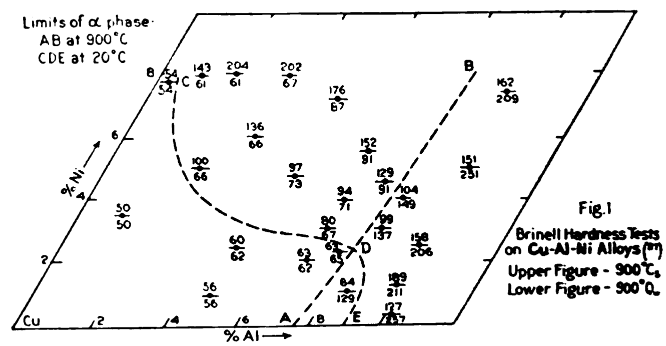

Fig. 1
Brinell Hardness Tests on Cu-Al-Ni Alloys (21)
Upper Figure - 900°C_s
Lower Figure - 900°Q_w

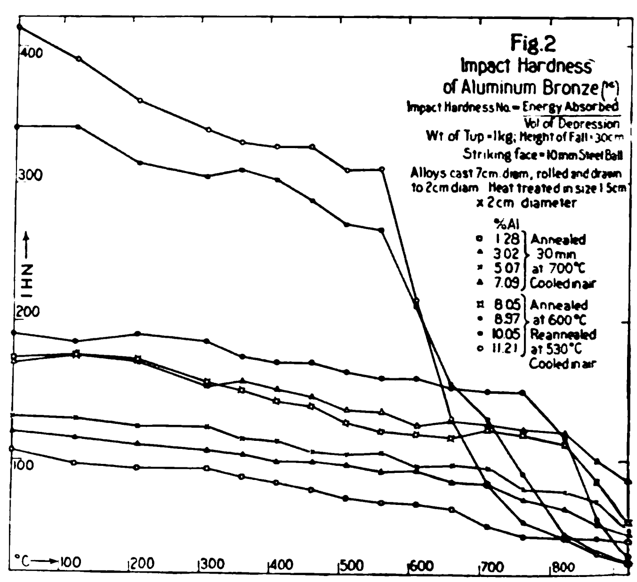

Fig. 2
Impact Hardness of Aluminum Bronze (22)
Impact Hardness No. = Energy Absorbed / Vol of Depression
Wt of Tup = 1kg; Height of Fall = 30cm
Striking face = 10mm Steel Ball
Alloys cast 7cm diam, rolled and drawn to 2cm diam. Heat treated in size 1.5cm x 2cm diameter

Table 32.—Brinell Hardness Number* at High Temperatures (12)

% Al	% Ni†	t,°C	20	250	350	450	550	600	700	800	900	950
7.22	4.01		89	83.8	81.9	79	76.5	65	39	21.5	12.5	9

* 10 m, 500 kg.

† Trace of Fe present.

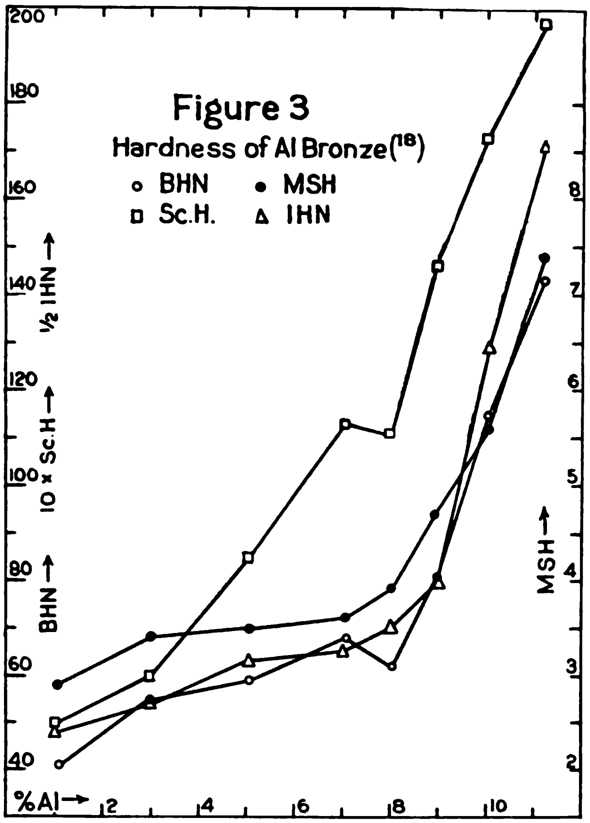

Table 33.—Brinell Hardness Number of Specimens Cooled at Different Rates (21)

% Al	% Ni \ τ	Q_w	2	10	35	50	95	145	200
5.32	4.84	73	71	77	97	116	117	129	120
5.21	7.31	87	84	154	176	168	148	159	145
5.34	7.34	88	83	156	180	167	156	152	148
6.93	5.62	91	90	148	152	152	140	139	137
7.91	4.64	91	87	129	129	131	137	146	125

τ = Time in minutes taken to cool from 900 to 700°.

Cu-Al-P

Table 34.—Cu-Al-P Alloys (20)

Wt. % Al	Wt. % P	M. P., °C	Trt*	*UTS*	*YP*†	*El*$_a$	*RA*	*BHN*‡	*ScH*	No. bends
5.12			G_m..........	29.5	7.9	68.0	58.2		8.5	
5.02		1054	A..........	38.5	9.5	79.1	79.0	77	9.0	741
			D_c..........	42.9	27.4	64.0	75.1	114	17.0	773
4.97	0.06		G_m........						9.0	
			A..........	39.1	10.1	75.9	77.1	75	9.0	736
			D_c..........	49.3	37.8	45.4	70.4	149	27.0	668
5.20	0.25	1045								
4.96	0.25		G_m..........	28.5	8.5	35.2	31.5	74	9.0	
5.14	0.52	1042	G_m..........	33.8	9.9	35.2	37.8	79	10.0	
5.30	0.75		G_m..........	31.5	10.7	19.6	20.8	89	12.5	
5.28	1.02	1030	G_m..........	24.7	14.5	9.7	13.0	94	13.7	
10.06		1038	G_m........						20.0	
			A..........	48.5	24.6	5.1	7.0	127	21.5	38
			D_c..........	69.6	66.1	9.0	12.4	186	33.0	231
10.07	0.03		G_m........						19.5	
			A..........	51.4	26.0	6.8	5.5	158	23.0	36
			D_c..........	71.8	69.9	6.7	8.4	196	35.0	327
10.27	0.18	1025	G_m..........	42.8	8.8	8.3	13.4	156	24.5	
9.95	0.40§		G_m..........	40.8	12.6	11.1	17.0	130	20.0	
9.70	0.50§	1019	G_m..........	29.5	9.1	3.9	9.2	133	22.5	

* A = A 800°/10 C_{gm}.

† By autographic recorder.

‡ 10 mm, 300 kg.

§ Distinct smell of PH_3 on turning down.

Cu-Al-Si

Table 35.—Hardness (*BHN*) of Cu-Al-Si Alloys (12)

% Al	% Si \ t,°C	20	250	350	450	550	650	750	850	900
2.54	2.59	59.4	51	48.4	40.2	32.4	20	15	10.6	
5.61	1.31	34.4	25.8	23.6	29.4	26.1	28	17.2	14.5	6.3

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Corse and Comstock, *40*, **10**: 119; 16. (11) Greaves and Jones, *47*, **34**: 85; 25. (12) Guillet, *74*, **21**: 295; 24. (13) Kent, *Mech. Eng. Handbook*, 10th ed., p. 500. N. Y., Wiley, 1923. (14) Lussana, *59*, **19**: 182; 10. (15) Marks, *Mech. Eng. Handbook*, 2nd ed., p. 574. N. Y., McGraw-Hill Book Company, Inc., 1924. (16) Matsuda, *159*, **13**: 401; 25. (17) Matsuda, *159*, **14**: 343; 25. (18) Matsuda and Shiba, *159*, **13**: 413; 25. (19) Portevin and Arnou, *74*, **13**: 101; 16.

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Ag, Au, Hg, Ir, Os, Pd, Pt, Rh, Ru, AND THEIR ALLOYS

Thomas K. Rose

Table 1.—Mechanical Properties

Ag

(D_d) (2, 6, 14, 18, 50, 74, 101)						(A,R)	*BHN*	25	38	51	68
t, °C	−252	−182	15	100	200	(24)	*UTS*	8.5	10.5	15	30
UTS	64	53	31	23	18.5		*El*	31	12	4	4

(DA) (2, 48, 101)									
t, ° C.	15	100	150	200	250	300	350	400	460
UTS	17	16	13.6	11.4	8.9	7.1	6.0	5.2	4.8

Trt	*UTS*	*YP*	*PL*	El_a	*RA*	Lit.
G_s	10.8	2.4	0.74	41	37.7	(87, 91)
G_m	11.5	3.3	1.8	59.5	66.7	

Trt	*UBM**	*No. B**	*UWB**	*IS*†	YP_C	Lit.
G_s	1.91	11.8	30.4		2.4	(87)
G_m	1.99	17.1	53.9	2.74	1.9	

	Trt \ $-100\frac{\Delta l}{l_0}$	5	10	20	40	Lit.
CS	G_s	5.8	10.2	18.7	33.9	(87)
	G_m	6.3	11.5	20.5	35.3	

Trt	G_m	G_s	R_d	
ScH‡	7–12	8	48	*MSH v.* Ag-Au
Lit.	(78, 87)			

A at:	125°	150°	300°	460°	105°	Lit.
For:	30 m	1 h	30 m	30 m	120 h	(78)
ScH‡	31	16	14.5	7	16.5	

(G) *BHN*§ = 30 (24.6–42) (15, 24, 29, 39, 43, 45, 49, 87).
(R, A) *BHN*§ = 30 (24.4–37) (15, 24, 42, 85).
(R_d) *BHN* = 89.7 (24).

t, °C	−38	0	40	80	140	Lit.
BHN‖	37.5	36.0	34.6	33.5	32.0	(29)

t, °C	18	200	Lit.
BHN§	29.3	27.1	(39)

Ag-Al; for *BHN v.* Fig. 2

Table 1.—Mechanical Properties.—(*Continued*)

Ag-Au

% Au	0	15	30	50	Lit.
MSH	50.8	72.8	90.9	97.4	(44)

For *LCH v.* Fig. 5.

Ag-Cu; *v. also* Fig. 3 for *BHN*

Ag, 92.5; Cu, 7.5 (standard or sterling silver) (87)

Trt	*UTS*	*YP*	*PL*	El_a	*RA*
G_s	22.2	12.8	7.4	41	54.6
G_m	17.2	13.4	6.2	6.75	15.8

Trt	*UBM**	*No. B**	*UWB**	*IS*†	YP_C
G_s	3.46	10.8	59.4	1.88	12.3
G_m	3.37	3.4		2.21	20.2

	Trt \ $-100\frac{\Delta l}{l_0}$	5	10	20	40
CS	G_s	19.8	25.7	37.5	49.9
	G_m	27.4	33.2	41.1	53.5

Trt	*ScH*	*BHN*¶	Lit.	(D_d)
G_s	18	60	(87)	*UTS* = 43
G_m	21–24	63		(74)

G_mR (1.125 in. to b in. thick) (87)

10^3 b	500	250	125	53	42
ScH‡	54	60	68		83
BHN¶	135	157	170	181	183

Ag, 92.5; Cu, 5.75; Cd, 1.75 (87)

Trt	*ScH*	*BHN*¶
G_s	22	73
G_m	23	74

	Trt \ $-100\frac{\Delta l}{l_0}$	5	10	20	40
CS	G_s	17.4	22.7	37.8	51.7
	G_m	18.3	23.8	35.8	60.1

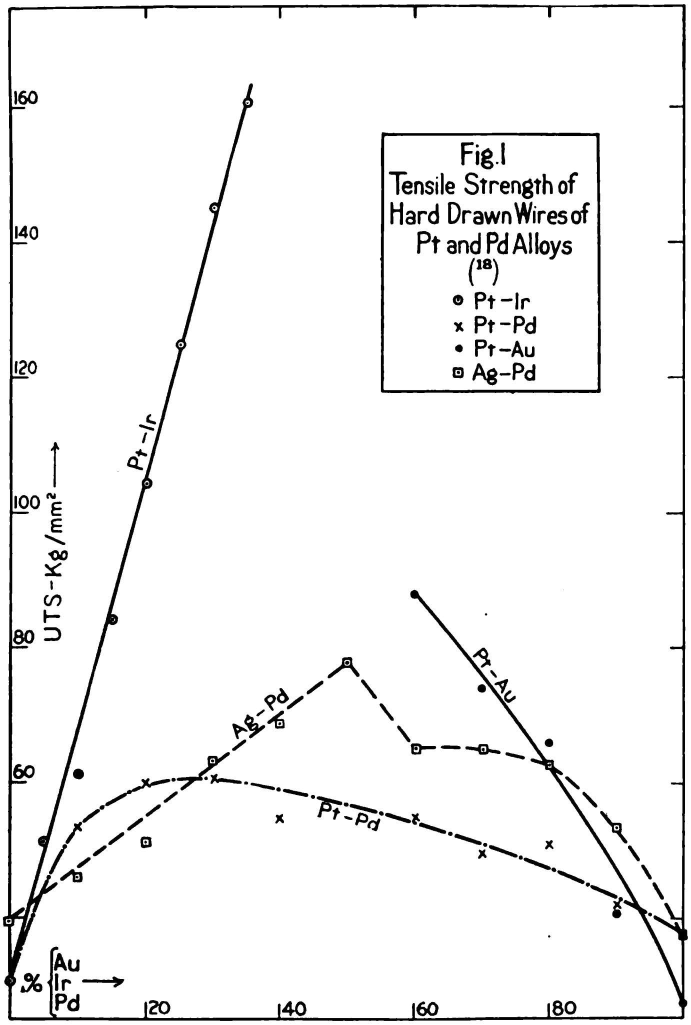

Fig. 1 Tensile Strength of Hard Drawn Wires of Pt and Pd Alloys (18)

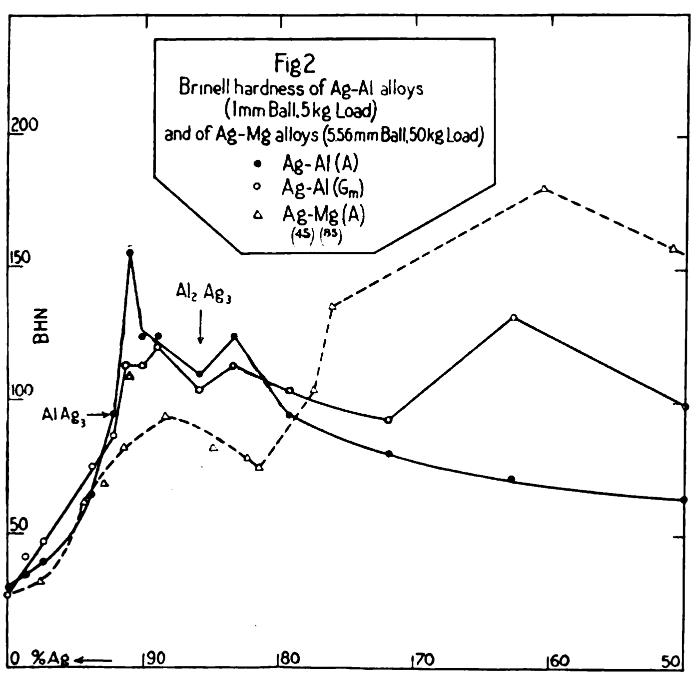

Fig 2 Brinell hardness of Ag-Al alloys (1mm Ball, 5kg Load) and of Ag-Mg alloys (5.56mm Ball, 50kg Load) (45) (85)

Table 1.—Mechanical Properties.—(*Continued*)

G_mR (1.125 in. to b in. thick)

10^3 b	500	250	125	53	42
ScH‡	53	57	67		75
BHN¶	134	150	164	173	173

Trt	*UTS*	*YP*	*PL*	El_a	*RA*
G_s	20.7	9.9	3.6	4.0	49.7
G_m	13.3	8.9	2.5	9.0	21.4

Trt	*UBM**	*No. B**	*UWB**	*IS*†	YP_C
G_s	3.25	12.1	59.4	2.40	10.7
G_m	3.58	25.1	138.3	2.74	11.0

Ag-Cu (G), 10 × *BHN* (9.5 mm Ball); Effect of Rate of Cooling (42)

% Cu / Load	5.2	13.0	23.0	28.2		33.0	50
100 kg	415 A	607 C_q	600 C_q	1169 C_q	520 C_s	572 C_s	560 C_s
500 kg	356 A	763 C_q	945 C_q	618 C_r	425 A	1005 C_q	725 C_q

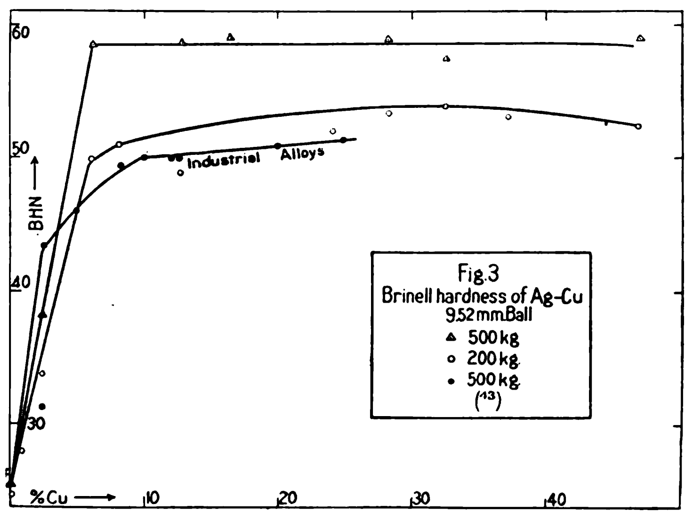

Fig. 3 Brinell hardness of Ag-Cu 9.52mm Ball (43)

	% Cu / Trt	7.5	8.3	10.0	16.5	20.0	28.0	Lit.
ScH‡	R_d	56	71	73	75	76	77	(78)
	A	20	23	23.5	28.5	31	28.5	

Ag, 83.5; Cu, 16.5 (G), *BHN* = 68; (10 mm, 1000 kg) (24)

Ag-Cd; Ag-Mg; Ag_2Te

Compound	*BHN*	Lit.
Ag-Cd	74.1	(45)
Ag-Mg *v. also* Fig. 2	68–76	
Ag_2-Te	25.8	

Ag-Pd; for *UTS v.* Fig. 1

		50	100	200	Lit.
Ag_3-Sn (10 mm ball)	*P*, kg	50	100	200	Lit.
	BHN	47.8	62.5	73.1	(45)

UCS of Ag-Sn amalgams *v.* (19).

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

Au, Pure

(D_d) (2, 6, 14, 101)					Trt	*UTS*	Lit.
t, °C	−182	15	100	200	DA	10	(101)
UTS	31.7	25	15.8	13.1	G	11.0	(2, 73)

Trt	G	R_d	RA, 107°	RA, 115°	RA, 122°	RA, 129°	RA, 150°	Lit.
*ScH**‡	5	30	24	17	8	7	6	(79, 80)

(G_m) El_b = 30.8 (73); for *LCH*, *v.* Fig. 5.

(RA) *BHN* = 25 (13.6–33) (15, 24, 42, 46, 64); (R_d) *LCH* = 61 (79).

Au (impure) (G_m) (73); *v. also* Fig. 5 for *LCH*

100 × %	20 Ag	19 Al	21 Bi	20 Cd	19 Cu	29 In
UTS	11.2	13.9	0.8	10.8	12.9	12.55
El_b	33.3	25.5	*ca.* 0	44.0	43.5	26.5
RA		46	0			72

100 × %	20 K	20 Li	20 Mn	24 Pb	20 Pd	20 Rh
UTS	<0.8	13.9	12.55	6.5	11.2	12.2
El_b	*ca.* 0	21.0	29.7	4.9	32.6	25.0
RA	0	60		*ca.* 0	75	

100 × %	20 Sb	20 Sn	19 Te	19 Tl	20 Zn	20 Zr
UTS	9.0	9.75	6.1	9.75	11.8	
El_b		12.3	*ca.* 0	8.6	28.4	12
RA	54		0	15	74	

Au-Ag

% Ag	0	15	35	50	Lit.
MSH	44.5	78.1	88.7	97.4	(44)

For effect on scleroscope hardness of small amounts of Ag, Cu, H, *v.* (79).

ScH (79)

% Ag \ Trt	R_d	A 250°	A 450°
8.3	41	41	7
25.0	49	43	10
50.0	47		10
62.5	49	39	11.5

Au-Ag-Cu (nuggets) (104)

% composition			*BHN*		
Au	Ag	Cu	Natural	(A)	(Pr)
92.46	6.82	0.23	33.0	19.2	
89.25	9.30	0.50	44.5	19.5	38–42
79.3	17.3	3.4	34.0	20.8	

Au-Cd

For *BHN* *v.* Fig. 2, p. 549.

Au-Cu

% Cu	0	10	20	30	40	50	60	70	80	90	Lit.
*IS***	11.5††	16.5	2	3	4.5	9.5	8	11.5	9.5	7	(64)

% Cu	0	15	35	50	Lit.
MSH	44.5	65.5	93.0	107.1	(44)

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

(4, 35, 75)			*ScH* (78)		
% Cu	*UTS*	Trt	G	R_d	A
8.3	28.3	G	23	65	23
10.0	45.8	D_d		69	29
16.6	35.1	G	For *BHN*; *v.* Fig. 4		

Au-Cu-Ag (99)

% composition \ Trt		G	AQ	R_d	G	AQ	R_d
Cu	Ag	*ScH*‡			*BHN*		
27.5	10	48	44	75	160		
25	25	66	48	73	205	159	
40	10	36		75	123		245

Au-Cu-X (G) (99)

% composition	*ScH*	*BHN*
Au, 50; Cu, 48; Al, 2	20	88
Au, 50; Cu, 48; Ni, 2	22	91

Au, 58; Cu, 30; Ag, 12, (D_d) *UTS* = 102.0 (9)

Au-Ni (42)

% Ni	Trt	*BHN*‡‡	% Ni	Trt	*BHN*‡‡
0	C_s	13.6	23.5	C_q	235
9.5	C_s	84.0	23.5	Q, A 72 h	140
20	C_s	191.5	30	C_s	183
23.5	C_s	205	40	C_s	159
23.5	C_r	150			

Au-Pt

For *UTS* *v.* Fig. 1.

Cu-Au-X (80)

% Comp. \ Trt		G	R_d	A 650°
Au	Ag	*ScH*‡		
20	50	36	86	
25	20	31	81	
25	15	29	78	
25	10	25	71	
25	9§§	28	72	
40	30	65		
40	10	34	94	46
40	0	21	84	38

% Comp. \ Trt		G	R_d	A 650°
Au	Al	*ScH*‡		
40	4	22	90	
40	6	26		
Au	Ni			
25	5	22	66	
25	2.5	23	63	
30	5	26	70	
40	2.5	23	72	
40	5	25	83	43
40	10	32	93	40

Hg-X (amalgams)

Effect of time on hardness‖‖ (90)

Hours after mixing	*BHN*¶¶			
	92.5 % Cd	95.0 % Pb	94.8 % Sn	75.0 % Zn
0.25	23.9	12.1	15.4	25.5
6			21.3	
24	31.2	13.6	22.6	76.0
48	31.2	13.6	23.2	76.0

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

Hardness of Tl-Hg

	*BHN**** (68)	
% Hg \ Load	50 kg	100 kg
0	1.57	
1	3.19	
3	4.15	4.85
5	4.99	5.12
7	3.60	3.85
9	3.66	3.93
11	3.18	3.36

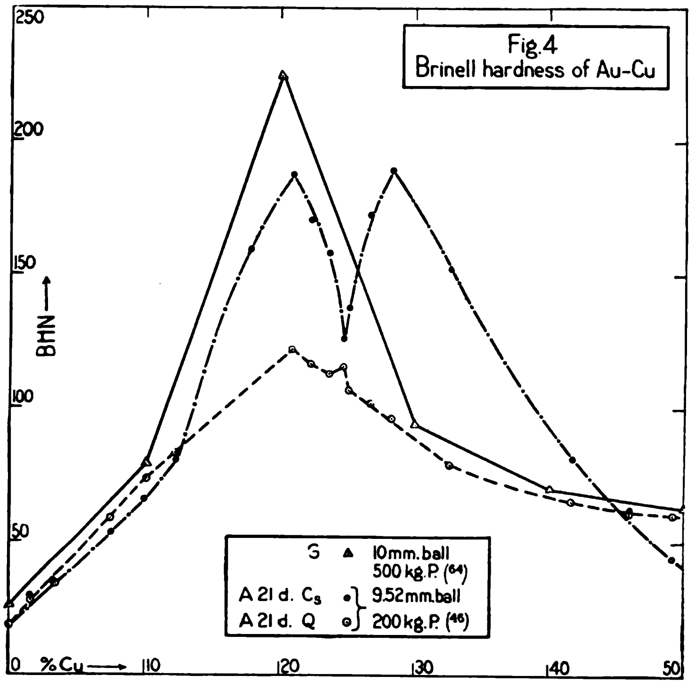

Fig. 4 Brinell hardness of Au-Cu

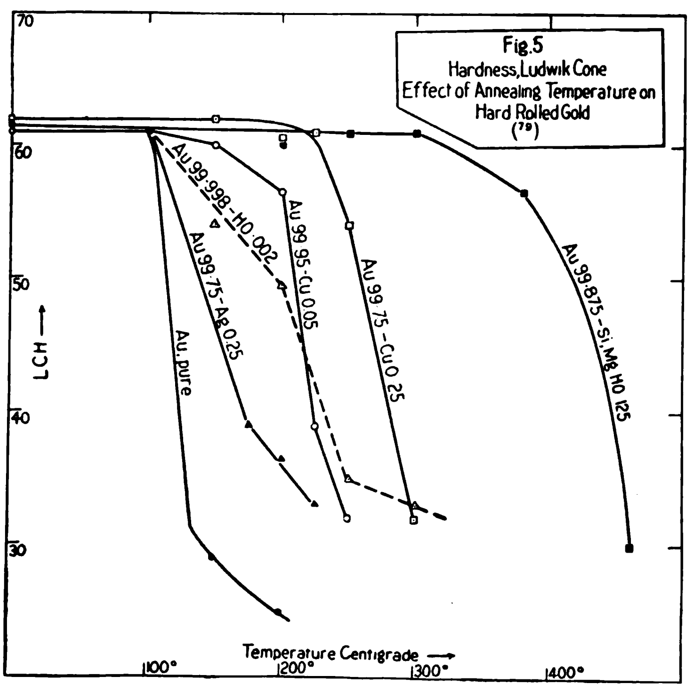

Fig. 5 Hardness, Ludwik Cone Effect of Annealing Temperature on Hard Rolled Gold (79)

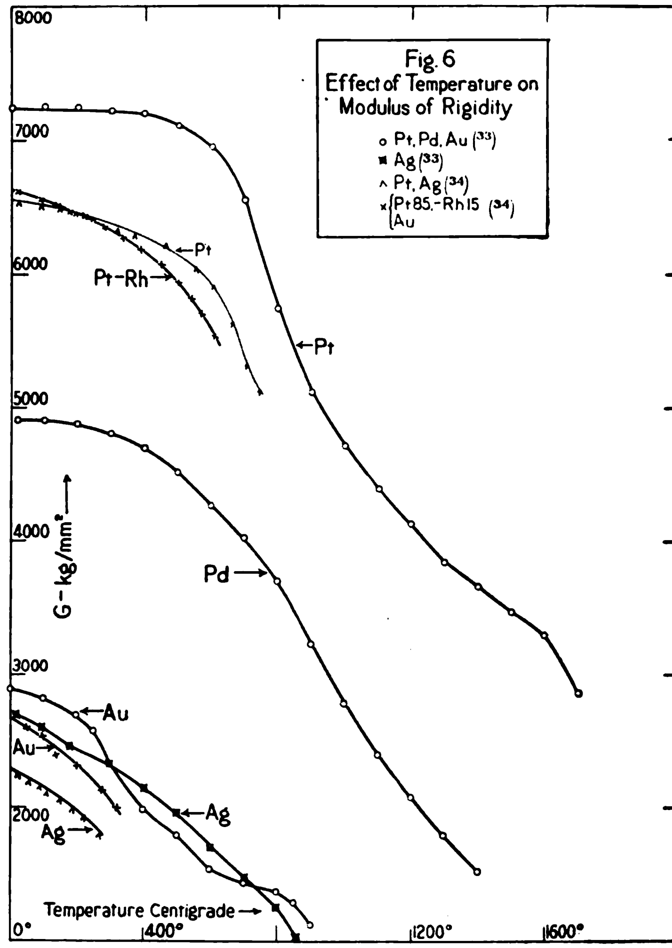

Fig. 6 Effect of Temperature on Modulus of Rigidity

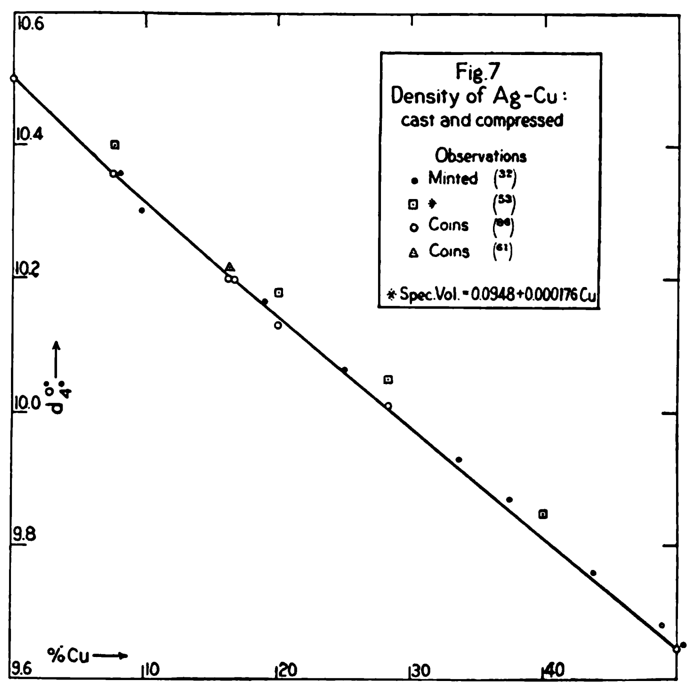

Fig. 7 Density of Ag-Cu: cast and compressed

TABLE 1.—MECHANICAL PROPERTIES.—(*Continued*)

For effect of time on hardness of other, less hard amalgams of Cd, Pb, Sn, Zn; also for hardness of amalgams of Cu (*BHN*, max. at 35% Cu) and Ag-Sn amalgams (*BHN*, max. at 60% Ag, 22% Sn), *v.* ([90]).

For *UCS* of Ag-Sn amalgams, *v.* ([19]).

Ir

BHN of cast Ir = 172 ([10]).

Pd

UTS of hard drawn wire = 38 ([18]); = 27.4 ([9]).
BHN of cast Pd = 49 ([10]).
For *UTS* of Pd-Ag, Pd-Pt, *v.* Fig. 1.

Pt

BHN ([103])

Source or Trt \ Load, kg	100	200
Heraeus	31	34
Russian	40	46
Pure (Hm)	60	64
Pure (A)	24	26

UTS of D_d wire = 34 ([9, 18, 47, 56, 101]); of A wire = 24.5 ([9, 47, 101]).

Trt	G	A 300°	A 650°	Lit.
BHN	117	121	46	([10])

Nuggets: Natural state, *BHN* = 105–108; annealed, *BHN* = 86–88 ([104]).

Pt-Ir (*BHN*)

Trt \ % Ir	1	5	10‡‡‡	15	20	25	30	Lit.
H_{wk}	117	170	220	280	330	370	400	([10])
A 1150°	47‡‡‡	110‡‡‡	150	190	230	270	310	

% Ir \ Load, kg	100	200	Lit.
1	25	27	([103])
2.5	32	35	

For *UTS* of Pt-Ir, Pt-Pd, *v.* Fig. 1.

Pt-Os

Os has about 2.5 times the hardening effect of Ir ([10]).

Pt-Rh

Pt, 90; Rh, 10 (A); *BHN* = 90 ([10]).

Rh

BHN of cast Rh = 139 ([10]).

Ru

BHN of impure cast Ru = 220 ([10]).

* Sankey machine: Test piece, 3/8 in. diam; length between jaws = 1.75 in.; angle of bending = 45¾ deg. *No. B* = Number of bends.
† Charpy machine: Standard 10 × 10 mm specimen, 40 mm span, 5 mm keyhole notch.
‡ Magnifier hammer.
§ *BHN* determined with 10 mm ball, 400–100 kg load, or with smaller ball and equivalent loads. In all cases loads are less than the standard $P = 30\ D^2$.
‖ 10 mm; 500 kg.
¶ 3.96 mm, 210 kg.
** Guillery machine.
†† Test piece bent, no sign of fracture.
‡‡ 9.52 mm ball, 500 kg load.
§§ Contains 1 % Ni.
‖‖ At 20°C.
¶¶ 2 mm ball, 8.7 kg load.
*** 10 mm ball, *BHN* = load ÷ area of impression.
††† 10 % Ir (G) *BHN* = 170.
‡‡‡ A 1000°.

TABLE 2.—ELASTIC PROPERTIES

Ag; *v. also* Fig. 6

Trt	D_d			DA	Lit.	Trt = D	Lit.
t, °C	15	100	200	15	([20, 21, 59, 93, 95, 101])	*G* = 2650 (2470–2940)	([21, 27, 28, 33, 38, 41, 63, 82, 89, 94])
E	7900	7274	6374	7300			

λ = 0.37 (DA) ([1, 7, 22, 34, 47, 81, 83, 93]); λ = 0.39 (D_d) ([93]).

Ag, 66.6; Pt, 33.3 ([93, 95])

(D_d): *E* = 10000, *G* = 3023. (A): *E* = 10510, *G* = 3699. λ = 0.42.

Au; *v. also* Fig. 6

Trt	G	D_d	A			Lit.	Trt = D	Lit.
t, °C			15	100	200	([20, 21, 59, 60, 93, 96, 101])	*G* = 2600 (2495–3950)	([20, 27, 28, 33, 38, 41, 89, 96])
E	7580	8000*	5584	5408	5482			

λ = 0.42 ([34, 47]).

Ir

E = 52700 (D_d) ([20]).

Pd; *v. also* Fig. 6

Trt	D_d	A	Lit.	G	Lit.
E	12000†	9750	([20, 21, 37, 82, 98, 101, 102])	4500 (4000–5210)	([21, 37, 38, 82, 101])

λ = 0.39 ([33, 47]).

Pd saturated with H_2

E = 13.2% (10–21%) < *E* for pure Pd. *G* = 12.7% (10.0–16.5%) < *G* for pure Pd ([37]).

Pt; *v. also* Fig. 6

Trt	D_d	A			Lit.	Trt = D	Lit.
t, °C		*ca.* 15	100	200	([20, 22, 55, 59, 82, 93, 95, 101, 102])	*G* = 6550 (6150–6930)	([21, 27, 28, 38, 41, 63, 82, 94])
E	17000‡	15200§	14178	12964			

λ = 0.38 ([22, 33, 47]).

Pt, 85; Rh, 15

G = 6600 ([28]); *v. also* Fig. 6.

Rh

E = 30000 (D_d) ([20]).

* (7780–8630).
† (10000–14300).
‡ (16080–17900).
§ (14900–15600).

TABLE 3.—EFFECT OF TEMPERATURE ON ELASTIC PROPERTIES

See also Fig. 6

Metal	Ag	Au	Pd	Pt	Rh	Lit.
$E_{0\ abs}/E_{0°C}$	1.37	1.32	1.27	1.27	1.18	([55])

Metal	$100\frac{E_0 - E_{100}}{E_0}$	Lit.	$100\frac{G_0 - G_{100}}{G_0}$	Lit.	$100\frac{\lambda_0 - \lambda_{100}}{\lambda_0}$	Lit.
Ag	3.97; $-\Delta E$ for 100° = 7.65 % ([82])	([33])	7	([20, 27, 28, 33, 38])	14	([7, 33])
Au	3.6 (2.92–4.09)	([33, 97, 101])	3	([27, 28, 33, 38, 82])	25	([33])
Ir			4	([20])		
Pd	2	([33, 82])	3	([20, 37, 38, 82, 101])		
Pt	$-\Delta E$ for 100° = 0.73 %	([82])	1 (0.14–1.78)	([27, 28, 38, 82])	5.5	([33])
Rh			3.7	([20, 21, 22, 82, 83])		

Table 4.—Compressibility of Ag-Au (4)

For compressibility of pure metals, *v.* vol. III.

100 × % Ag	0	116	586	1415	2317	3399	4773	6771	8555	9649
$10^8\chi$	155	140	160	126	111	113	113	130	134	146

$$\chi = \frac{1}{V_0}\frac{\Delta V}{\Delta p} \text{ where } \Delta p = 1 \text{ atm.}$$

Table 5.—Specific Volume of Alloys

System	10^5a*	10^7b*	Range† of observations, %	Max. error, %	Intersection‡	Lit.
Ag-Au	9500	−4309	0–100	+0.2		(53)
Ag-Bi	9550	630	0–100	−0.4		(53)
Ag-Cd	9700	1034	17–46	−0.4		(54)
Ag-Cu	9480	1760	0–100	+0.7		(53)
Ag-Pb	9551	−760	0–100	+0.7		(53)
Ag-Pd	9533	−1386	0–40	+0.7	52	(58)§
	9244	−844	60–100	±0.2		
Au-Cu	5191	6050	0–100	+0.7		(53)
Au-Pb	5191	3599	0–100	−1.0		(53, 57)
Au-Sn	5191	8520	0–100	−1.5		(53)
Hg-In	7385	5830	0.4–1.9	±0.04		(70)§
Hg-Pb	7368	1422	0–100	−1.0		(53)
Hg-Sn	7368	6345	0–100	−0.9		(53)
	7368	6212	0–100	+0.8		(10, 26, 40)§
Hg-Tl	7368	1238	0–43	±0.1	66	(66, 70)
	7674	772	80–100	−0.2		(68)§
Hg-Zn	7368	6556	0–48	+0.5	56	(12, 54)§
	7006	7212	60–100	+0.1		
Ir-Pt	4461	190	0–100	±0.2		(53)

* Specific vol. = a + bx, where x = % by weight of second metal in formula of the alloy system.

† Per cent of second metal.

‡ Where the results are best represented by two straight lines, the point of intersection is given.

§ Line determined from data given in literature reference.

Table 6.—Specific Gravities of Alloys

For specific gravities of pure metals, *v.* p. 456

% composition	Treatment, description	Test temp., °C	Ref. temp., °C	d*	Lit.
Ag-Au	*v.* Fig. 8 and Table 5				
Ag, 67.5; Bi, 32.5	G (*v.* also Table 5)	15.1	15.1	10.323	(26)
51 49	G (*v.* also Table 5)	13.2	13.2	10.197	(26)
Ag-Cd	*v.* Table 5				
Ag, 92.5; Cu, 7.5	R_d	15	4	10.34$_{85}$	(78)
	A 700°	15	4	10.24$_{69}$	(78)
	Coin	13		10.37	(77, 86)
Ag, 83.5; Cu, 16.5 (*v. also* Fig. 7 and Table 5).	G	18.5	18.5	9.99932	(61)
	A	18.5	18.5	10.00206	
	AR	18.5	18.5	10.20244	
	ARA	18.5	18.5	10.20251	
	ARAR	18.5	18.5	10.20759	
	ARARA	18.5	18.5	10.21648	
	Same, struck	18.5	18.5	10.21636	
	French coin	15		10.16–10.20	(86)
Ag, 80.0; Cu, 20.0	Canadian coin	15		10.13	(86)
Ag, 71.9; Cu, 28.1	Molten			9.0554	(71)
	Netherlands gulden			10.011	(86)
Ag, 50.0; Cu, 50.0	English coin	13		9.640–9.642	(86)
Ag, 50; Cu, 41; Ni, 9	English coin	13		9.60–9.61	(86)
Ag, 67.6; Pb, 32.4	G (*v. also* Table 5)	13.5		10.800	(57)
51.1 48.9	G (*v. also* Table 5)	13.8		10.925	
Ag-Pd	*v.* Table 5				
Ag, 100; Sb, 0	All alloys show expansion, max. being at 25.4 % Sb			10.49	(54)
85.4 14.6				10.017	
74.6 25.4				9.682	
69.5 30.5				9.356	
Ag, 78.8; Sn, 21.2	G	14.8		9.953	(26)
Ag, 73.16; Sn, 26.84 (Ag_3Sn) Contraction of sp. vol. = 5 % (19).	Filings	25	4	9.80	(16, 36, 51)
	Same, A 100°	25	4	9.89	(36)
	In mass	0	4	9.86$_{90}$	(51)
	Filings	0	4	9.77$_{72}$	(51)
	Same, A 100°/2 h	0	4	9.80$_{88}$	(51)
	Same, A 350°/5 h	0	4	9.84$_{41}$	(51)
Ag, 70.8; Sn, 29.2	Maximum contraction of specific vol.				(53)
Ag, 65; Sn, 35	G	12.9		9.507	(26)
Ag, 54.7; Zn, 45.3	G			8.744	(54)
Au-Ag	*v.* Fig. 8 and Table 5				
Au Ag Cu					
87.5 7.5 5.0	Struck in coin press			17.14	(86)
62.5	15 carat gold ware†			13.22–14.08	(86)
Au, 65.4; Bi, 34.6	G	16		14.844	(26)
Au, 91.6; Cu, 8.3	British coin	15		17.48	(8, 76, 86)
90 10	Scandinavian coin	0	4	17.17$_{11}$	(8)
87.5 12.5	Egyptian coin			16.794	(86)
	v. also Fig. 8 and Table 5				
Au-Pb and Au-Sn	*v.* Fig. 9 and Table 5				
Hg-Ag	*v.* Fig. 10 and (19)				
Hg, 67.1; Au, 31.9				15.412	(13)
Hg, 32.5; Bi, 67.5				10.45	(13)
Hg-Cd	*v.* Fig. 10				
Hg-In	*v.* Table 5				
Hg-K, Hg-Li, Hg-Na	*v.* Figs. 11 and 11*a*				
Hg, 98.98; Pb, 1.02	*v. also* Table 5 and Fig. 12	20	4	13.536	(67)
99.316 0.684		20	4	13.539	
99.603 0.397		20	4	13.541	
Hg, 99.79; Sn, 0.21	*v. also* Table 5	20	4	13.529	(70)
99.70 0.30		20	4	13.519	
99.55 0.45		20	4	13.513	
Hg-Tl	*v.* Table 5				
Hg, 99.02; Zn, 0.980	*v. also* Table 5	25	4	13.4490	(12)
98.544 1.456		25	4	13.4054	
98.083 1.917		25	4	13.3628	
Ir-Pt	*v.* Pt-Ir				
Pd, 60.7; Pb, 39.3				11.225	(3)
Pt, 95; Ir, 5	A, struck repeatedly	0	4	21.474	(81)
90 10		0	4	21.55	(81, 88)
85 15	A, struck AR	0	4	21.594	(81)
66.67 33.33		10		21.874	(81)
5 95	*v. also* Table 5	13		22.384	(81)
Pt, 48.5; Pb, 51.5				15.736	(3)
Pt, 48.9; Tl, 51.1	G, pulverized	14	14	15.65	(23)

* If test temp. only is given, *d* is mass-density g/cm³; if ref. temp. is given also *d* is specific gravity, referred to H_2O at this ref. temp.

† *See* Index No. 635.

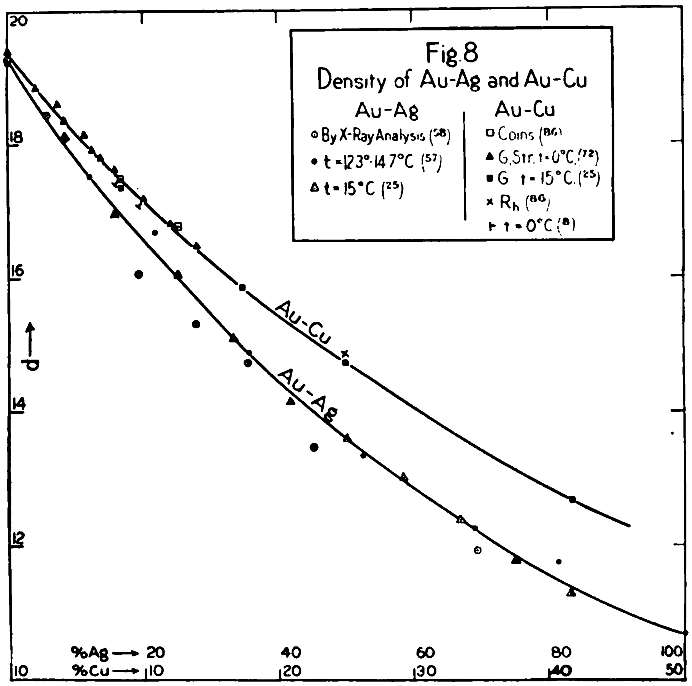

Fig. 8 Density of Au-Ag and Au-Cu

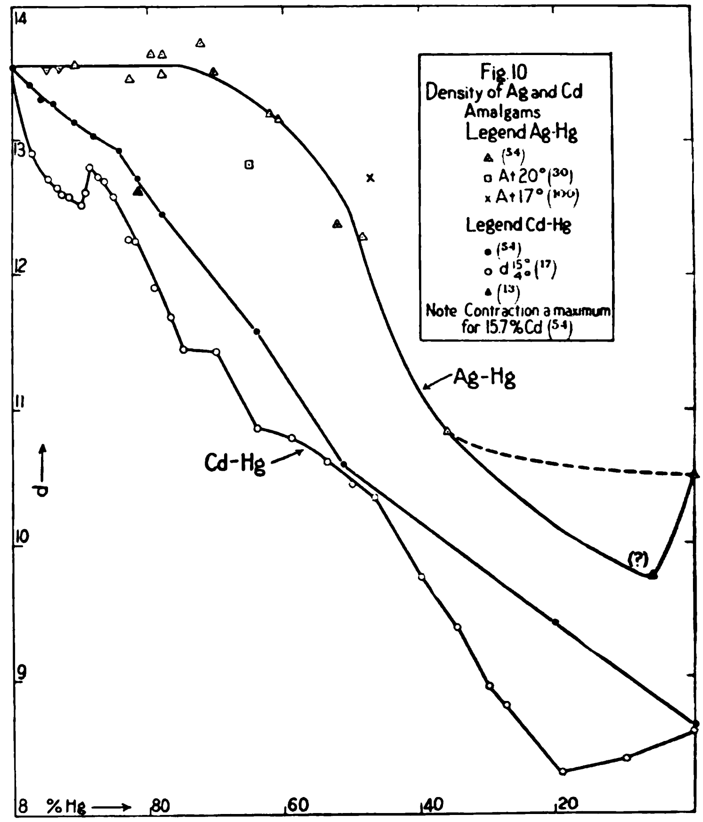

Fig. 10 Density of Ag and Cd Amalgams

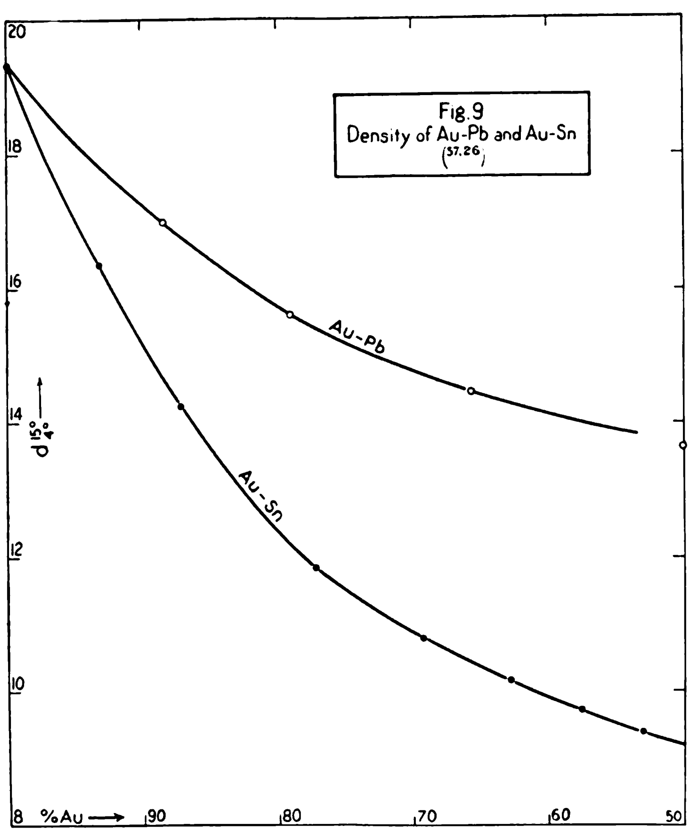

Fig. 9 Density of Au-Pb and Au-Sn (57, 26)

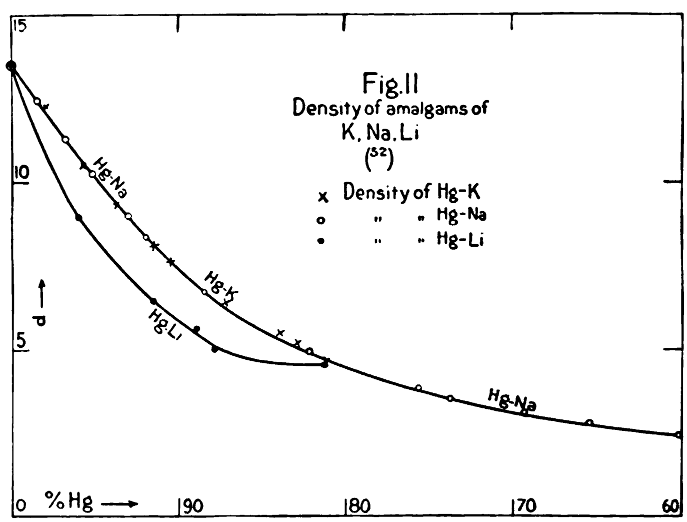

Fig. 11 Density of amalgams of K, Na, Li

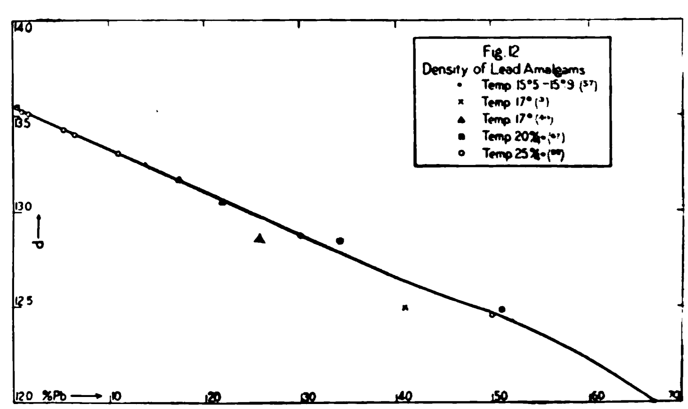

Fig. 12 Density of Lead Amalgams

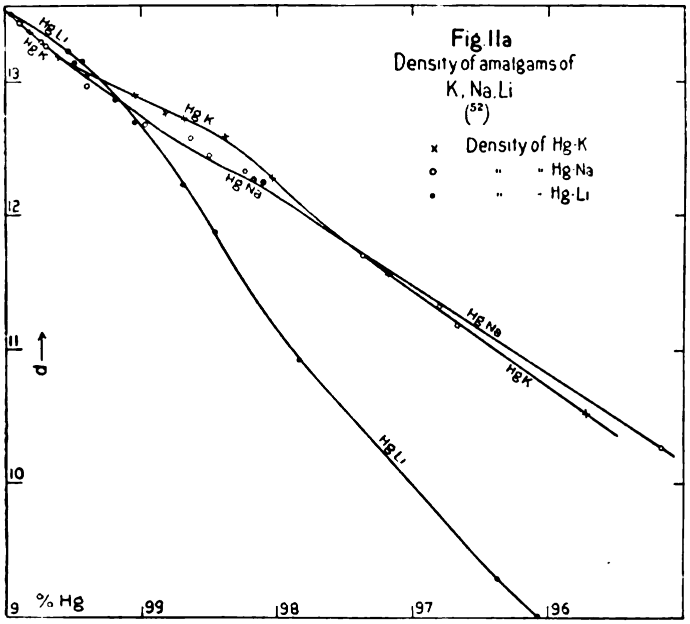

Table 7.—Surface Tension of Amalgams in Saturated Water Vapor at *ca.* 18°C (84)

For surface tensions of pure metals *v.* vol. III

Wt., %	a^2-cm^2	γ dyne/cm	Wt., %	a^2-cm^2	γ dyne/cm
Au, 0.0153	0.0656	435.5	Na, 0.00015	0.0655	435.5
0.0838	.0639	424.7	0.00067	.0639	424.2
0.122	.0639	424.7	0.00222	.0631	418.8
Ba, 0.00045	.0694	461.0	0.0490	.0596	393.3
0.0022	.0728	483.5	0.0670	.0594	391.3
0.0074	.0742	492.3	0.1240	.0591	386.4
Ca, 0.00020	.0659	436.5	Pb, 0.226	.0639	424.7
0.00100	.0689	458.0	0.936	.0626	415.9
0.00154	.0709	471.8	1.410	.0625	414.9
0.00274	.0713	473.7	Rb, 0.00157	.0654	434.5
0.00851	.0733	490.4	0.00313	.0651	432.5
Cd, 0.559	.0664	440.4	0.00778	.0555	368.8
1.204	.0675	446.3	0.04660	.0504	334.5
2.376	.068	447.2	Sn, 0.176	.0656	435.5
Cs, 0.00083	.0644	427.6	0.412	.0642	425.7
0.00160	.0607	403.1	0.868	.0644	425.7
0.00280	.0577	383.5	Sr, 0.00027	.0680	452.2
0.01310	.0505	335.4	0.00162	.0713	470.8
K, 0.00071	.0657	436.0	0.00372	.0725	481.6
0.00184	.0610	405.1	0.0153	.0753	500.2
0.00680	.0591	392.3	Tl, 0.0238	.0660	438.1
0.01350	.0586	388.4	0.0986	.0680	451.2
0.01500	.0577	382.5	0.490	.0683	453.1
Li, 0.0002	.0657	436.0	Zn, 0.661	.0660	437.1
0.0019	.0665	441.4	1.221	.0669	440.4
0.0056	.0678	450.2	1.750	.0671	440.4
0.0140	.0678	450.2			

Table 8.—Annealing and Quenching Temperatures

% composition	t_0*	t_{30}†	Lit.
Ag	100	150	(78)
Ag‡	230	265	(5)
Au, 37.5	250	450	(79)
Cu, 7.5	230	550	(78)
Cu, 8.3	230	600	(78)
Cu, 10.0	230	650	(78)
Cu, 16.5	300	650	(78)
Cu, 20.0	300	700	(78)
Cu, 28.1	300	700	(78)
Au	80	120	(78)
Ag (etc.), 0.03‡	200	280	(5, 79)
Ag, 0.004	150	200	(79)
Ag, 0.25	150	225	(79)
Ag, 8.3	275	450	(79)
Ag, 25.0	275	450	(79)
Ag, 50.0	300	450	(79)
Cu, 0.01	140	150	(79)
Cu, 0.25	175	300	(79)
Cu, 8.3§	250	500	(78)
Cu, 10.0	300	700	(78)
H_2, 0.002	150	300	(62, 79)
Pt	400	650	(10)
Ir, 0.1	450	1000	(10)
Ir, 10		1150	(10)
Ir, 20		1150	(10)
Ir, 25		1150	(10)

Au, 80; Cu, 20 to Au, 70; Cu, 30: Quench from 600° (46).

(Au + Ag), 80; Cu, 20 to (Au + Ag), 60; Cu, 40: Quench from 500° (99).

* t_0, °C of beginning of softening.

† t_{30}, °C of completion of softening in 30 minutes.

‡ Pure commercial.

§ Softens completely at 300° in 384 hr.

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GRAPHITE (*v. also* p. 468)

V. H. Stott

Ultimate tensile strength = 2 kg/mm² (4, 5).
Young's modulus = 836 kg/mm² (4, 5).

Specific Gravity

d_4^{20} = 2.25 to 2.26 (1).
d_4^{15} = 2.255 (after compression to 5000 atm.) (3).
d_4^{16} = 2.232 (after fusion in arc) (6).
M. P. = 3500° ± 100°C (2).
V. P. at triple point = 0.25 atm. (2).

LITERATURE

(For a key to the periodicals see end of volume)

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MECHANICAL PROPERTIES OF As, B, Ca, Ce, Co, Cr, Ge, In, K, La, Mo, Na, Pr, Ta, Th, AND W AND THEIR ALLOYS, AND OF ALLOYS CONTAINING Ba, Ga, Li, Mn, Rb, Si, Sr, Ti AND V

C. H. Desch

For specific gravity of the pure metals, *v.* p. 456; surface tension, *v.* vol. III; viscosity, *v.* vol. III; compressibility, *v.* vol. III.

Table 1.—Tensile Properties of Ca, Co, Mo, Ta, Th and W

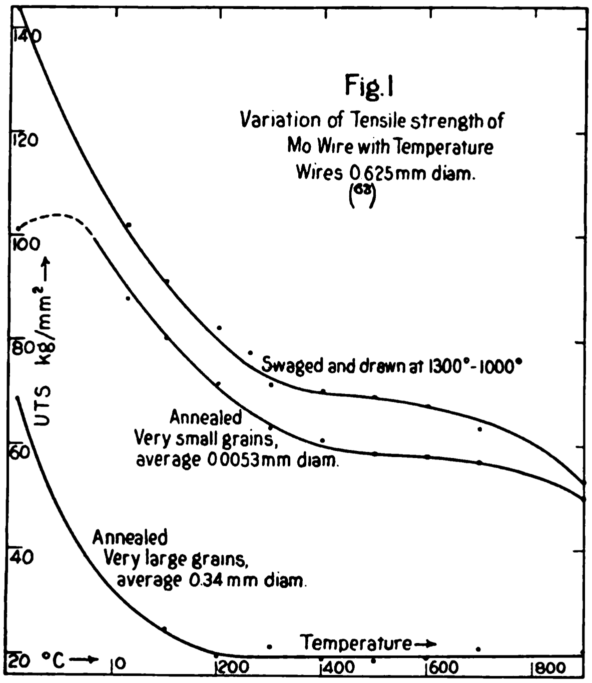
Metal	Treatment	*UTS*	*El*	*RA*	Lit.
Ca	Cast	6.12*	6†		(19)
Co	Cast‡	24			(34)
	Annealed§	26			
	Drawn wire	68	5	8	
Mo	Drawn wire (*v. also* Figs. 1, 2, 3)	180–220			(15)
	Sheet	70‖	43		(68)
Ta	Hard drawn wire	93			(61)
Th	Drawn wire	56.3			(55)
W	Hammered	150	4	28	(16)
	Drawn wire	420			(32)
	Drawn to mm diam.:				(16)
	0.45	186			
	0.18	240			
	0.145	256	*v. also*		
	0.10	339	Fig. 4		
	0.028	411			
	Rolled sheet	335			
	Single crystal wires			100	

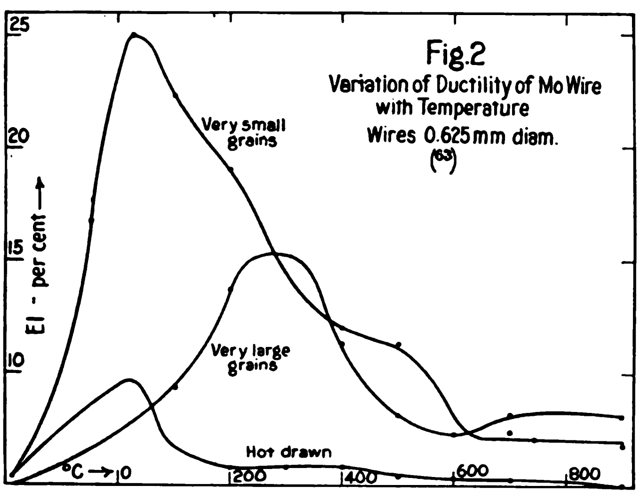
* Probably too high due to impurity.
† On 5 cm.
‡ *UCS* = 87; YP_C = 30 kg/mm².
§ YP_C = 39 kg/mm².
‖ *YP* just below *UTS*; *PL* = 46.

Table 2.—Hardness of As, B, Ca, Ce, Co, Cr, Ge, In, K, La, Mo, Na and Pr

Metal	Treatment	*BHN*	Ball diam. mm	Load, kg	*ScH*	*EP*, kg/mm²	Lit.
As	Metallic	147	10	1000			(14)
B	Usually described as nearly as hard as diamond.						
Ca		42*	10	500	19–20		(5)
Ce		28.0	5	90	26 (rolled) 9 (fresh cut)		(27) (23)
Co	Cast	124	10	1600			(34)
		86	10	1000			(14)
	Electrolytic†	270–311					(44)
Cr		91	10	500			(14)
Ge	Between 6 and 6.5 on Mohs' scale of hardness.						(8)
In		1.0	10	50		3.1	(14, 39)
K		0.037	10	1.6		0.25	(14, 39)
La		37	10	500			(36)
Mo		147			12 (rod) 35 (sheet)		(68) (68)
Na		0.07	10	3.2		0.3	(14, 39)
Pr	Electrolytic‡	25	10	500			(71)

* *v. also* (14).
† Probably contained H_2.
‡ About 99.7 % pure.





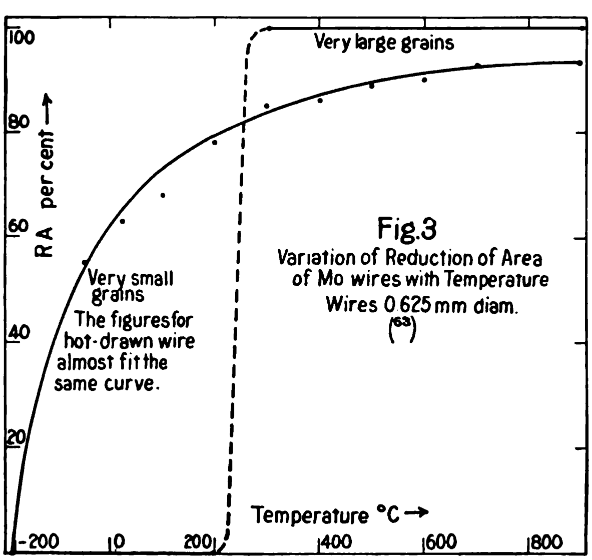


Table 3.—Properties of Co-Cr and Stellite

Typical compositions of stellite

Co	Cr	W	Mo	Fe	Si	Mn	V	C	Remarks	Lit.
34.6	26.3	12.7	9.4	10.1	0.78	0.72	1.0	1.79	(1914)	(21)
55.6	33.6	9.1		Tr.	0.17	0	0	1.48	(1917)	(21)
54.9	32.9	9.1		1.0	0.29				Stellite 2	(54)
52.9	23.8	17.6		5.2	0.62				Stellite 3	(54)
59.5	10.8	0	22.5	3.1	0.77	2.04		0.87		(26)
38	30	16	4	(Ni, 10)				2–5	"Akrite"	(59)

Brinell hardness of stellite

t, °C	15	100	200	350	475	630	700	800	Lit.
*BHN**	512	495	430	430	387	364	351	332	(21)

	As received	Quenched 1300°	Quenched 1000°	Lit.
Stellite 2	545	495	564	(26)
Stellite 3	590	594		

Co, 75; Cr, 25: *UTS* = 67 kg/mm²; *EL* = 56 kg/mm²; *El* = 3% (14).

* These data apparently for second alloy in above table.

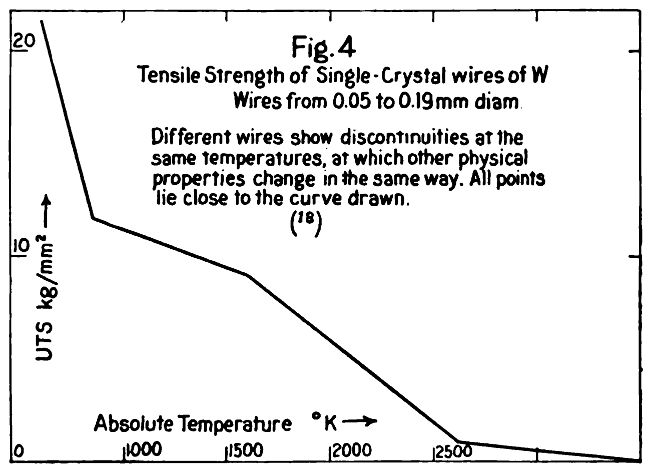


Table 4.—Hardness of Alloys

% composition	*t*, °C	Hardness, Mohs' scale	Lit.
As, 57; Cd, 43	20	3.5–4	(73)
Mn, 80; Si, 20	15	6.5	(43)
Mn, 66; Si, 34	15	8.5	(43)
Mo, 88.9; C, 11.1	20	7–8	(51)
Si, 54; Ti, 46	22	4–5	(29)
Zr, 61.5; Si, 38.5	22	6	(29)

% composition	*BHN*	Lit.
Ce, 87; Cu, 13	61*	(23)
Ce, 54; Cu, 46	152*	(23)
Co, 90; W, 10	282†	(35)

* 5 mm ball, 110 kg load.
† Maximum hardness for 25 % Co.

Table 5.—Extrusion Pressure of In-Pb and K-Rb

In-Pb (aperture 2.81 mm diam.) (38)

% In	0	5.8	14.1	27.0	35.8	45.2	56.4	84.3	100
EP	10.6	14.7	18.2	21.0	23.7	21.0	18.2	11.5	3.1

K-Rb (*t* = 22°C, aperture 2.86 mm diam) (37)

% Rb	0	9.4	12.8	26.7	31.2	55.7	67.2	85.6	90	96	100
10 *EP*	0.9	2.2	2.4	2.8	2.6	2.4	2.1	1.9	1.5	1.1	0.8

TABLE 6.—ELASTIC PROPERTIES OF TA AND W

Ta	$E = 1.9 \times 10^4$ kg/mm² (4)
W	$E = 3.62 \times 10^4$ kg/mm² at 20°C; $= 3.31 \times 10^4$ kg/mm² at 1000°C; dE/dt = constant (10). Nearly same value v. (16, 18, 72).
	$G = 1.51 \times 10^4$ kg/mm² at 20°C. dG/dt is negative, amount varying with recrystallization of the wire (18, 31, 58, 72).
	$K = 2.82 \times 10^4$ kg/mm² at 27°C; $= 3.62 \times 10^4$ kg/mm² at 642°C (72)
	$\lambda = 0.17$ (independent of temperature) (18).

TABLE 7.—SPECIFIC GRAVITIES OF ALLOYS

% composition	t, °C	d_4^t	Lit.
As, 55.5; Ca, 44.5	15	2.5	(41)
As, 62.8; Cd, 37.2	20	5.8_5	(73)
57 43	20	5.8_6	
55.7 44.3	20	5.9_2	
49.5 50.5	20	5.9_7	
As, 71.4; Co, 28.6	0	7.0	(11)
65.6 34.4	0	7.3	
56.0 44.0	0	7.6	
45.9 54.1	0	7.8	
As, 68.4; Cr, 31.6	22	6.2	(9)
59.0 41.0	16	6.3	
B, 62; Ca, 38	15	2.2	(53)
B, 57; Sr, 43	15	3.3	(53)
Ba, 73; As, 27	15	4.1	(41)
Ba, 67.7; B, 32.3	15	4.36	(53)
Ca, 55.3; Mg, 44.7	25	1.7	(2)
Co, 91.5; B, 8.5	20	7.9	(13)
Co, 89.27; Ni, 10.73	....	8.8_7	(3)
79.54 20.46	....	8.7_5	
69.77 30.23	....	8.7_7	
60.43 39.57	....	8.7_2	
Co, 79.2; P, 20.8	....	6.6	(74)
Co, 80.8; Si, 19.2	....	7.3	(42)
67.6 32.4	....	6.3	(66)
51 49	....	5.3	
Cr, 82.5; B, 17.5	15	6.1	(12)
87.7 12.3	15	6.7	
Cr, 91.4; C, 8.6	25	6.9	(56)
86.7; 13.3	21	6.6_8	
Cr, 50.8; W, 40.1; C, 9.1	22	8.4	(52)
Ga, 90; In, 10	20	5.9_5	(6)
K, 68.3; Na, 31.7	4.5	0.89_0	(22)
La, 85.3; C, 14.7	20	5.0	(46)
Mn, 97.0; C, 3.0	....	6.9_8	(62)
93.28 6.72	....	6.8_9	
Mn, 77.4; Mo, 22.6	0	7.3	(1)
69.5 30.5	0	7.8	
53.4 46.6	0	8.4	
36.4 63.6	0	8.6	
22.3 77.7	0	8.7	
Mn, 80; Si, 20	15	6.2	(43)
66 34	15	5.9	
49.3 50.7	13	6.2	
Mo, 94.1; C, 5.9		8.9	(47)
88.9 11.1	20	8.4	(51)

TABLE 7.—SPECIFIC GRAVITIES OF ALLOYS.—(*Continued*)

% composition	t, °C	d_4^t	Lit.
Mo, 77; Fe, 23	0	9.4	(67)
63 37	0	9.0	
53 47	0	9.2	
46 54	0	8.9	
Mo, 62.8; Si, 37.2	0	5.9	(30)
Na, 85.78; Hg, 14.22	17	1.12_5	(65)
79.9 20.1	110	1.17	
77.73 22.27	17	1.23_5	
71.0 29.0	110	1.28	
58.7 41.3	110	1.57	
56.35 43.65	17	1.71_6	
51.0 49.0	110	1.79	
Si, 96.5; Al, 3.5		2.4	(17)
85 15		2.4	
57 43		2.5	
Si, 58.7; Ca, 41.3		2.5	(49)
Si, 89.1; Cr, 10.9		2.6	(17)
75.8 24.2		2.9	
70 30		3.1	
65.3 34.7		3.3	
62 38		3.5	
57.8 42.2		4.0	
52.4 47.6		4.7	
51 49		4.8	
Si, 90.5; Cu, 9.5		2.5	(17)
69.6 30.4		3.0	
68 32		3.1	
51.6 48.4		3.6	
50.4 49.6		3.9	
Si, 95.0; Fe, 5.0	18	2.4	(25, 60)
79.4 20.6	18	2.7_5	
61.5 38.5	18	3.9	
51.8 48.2	18	4.4	
50.1 49.9	18	4.7	
Si, 71.8; Li, 28.2		1.1	(48)
Si, 66.8; Ni, 33.2		3.5	(17)
57.3 42.7		3.9	
52.6 47.4		4.2	
Si, 54; Ti, 46	22	4.0	(29)
Sr, 54; As, 46	15	3.6	(41)
Ta, 80.4; Si, 19.6	0	8.8	(30)
Th, 90.6; C, 9.4	18	9.0	(50)
Th, 80.5; Si, 19.5	16	7.9_6	(28)
V, 81; C, 19		5.4	(46)
W, 93.88; C, 6.12	18.5	15.6	(57, 69)
W, 73.6; Fe, 22.4; C, 4.0	18	13.4	(70)
W, 76.5; Si, 23.5	0	9.4	(7)
Zr, 61.5; Si, 38.5	22	4.9	(29)

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(For key to the periodicals see end of volume)

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FATIGUE OF METALS AND ALLOYS

H. J. Gough

The data on fatigue of metals and alloys are arranged according to the following scheme:

1. The chemical symbols of the principal constituents of each non-ferrous alloy are arranged in order of descending magnitude of their proportions in the alloy. Thus section 3 (Al-Cu-Mg-Si) contains alloys whose largest constituent is Al; the next largest Cu and the third largest is Mg, any other elements present having minor effect on the properties (*v. also* Introduction, p. 358). The sections are numbered consecutively.
2. The steels are arranged in the same manner except that C is written last in the type formula.
3. The different sections, each containing alloys of the same type formula are arranged in alphabetical order.
4. The alloys within each section are arranged in descending magnitude of proportion of largest constituent if this is given by analysis, if not, in order of ascending magnitude of proportion of second constituent; they are numbered consecutively in each section.
5. In the figures, the composition number of any alloy is the combination of its section number and number within the section. Thus the Al-Cu alloy containing 12% Cu has the composition number **2:4**.
6. In Tables 2–9, the alloys follow the same arrangement as in Table 1, which should be consulted for exact composition.

Table 1.—Composition of Alloys

Comp. No.	% composition, Al+ Cu	Fe	Mg	Mn	Ni	Si	Zn	Table
				1. Al				
1	0.12	0.49				0.15		3
2	(99.6% Al) Single crystals*							2, 5
				2. Al-Cu				
1	2.0			1.0				3
2	4.55	0.56		0.82		0.82		3
3	8.0							3
4	12.0	0.69				0.38	0.05	3
5	12.6	0.82				0.37	Tr.	3
				3. Al-Cu-Mg-Si				
1	3.25	0.28	0.70	Tr.		0.28	Duralumins	3
2	3.61	.74	.70	0.60		.48		3
3	3.75	.60	.26	.69		.40		3
4	3.88	.45	.78	.64		.26		3
5	4.0		.50	1.0		1.0		3, 9
6	4.18		.66			0.19		3
7	4.28	.54	.42	0.62		.34		3
8	5.0		.75	.5		.75		3, 9
9	6.0		.75	.5		1.0		3, 9

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

Comp. No.	% composition, Al+ Cu	Fe	Mg	Mn	Ni	Si	Zn	Table
4. Al-Cu-Ni-Mg								
1	2.0		1.0		1.5	0.6	"Magnalite"	3, 9
2	4.0		1.0		1.0			3
3	4.0		1.50		1.0			3
4	4.0		1.50	0.50	2.0	0.75	Ind. No. 1491	3, 9
5	4.0	0.20	1.50	0.50	2.0	.20	Modified "Y" alloy	3, 9
6	4.0	.20	1.50		2.0	.20	"Y"	3, 9
7	4.0		1.5		2.0		alloy	3
5. Al-Cu-Zn								
1	8.7	0.57				0.33	5.3	3
2	9.5	.75				.35	5.5	3
6. Al-Mg								
1		0.8	6.2	"Aeromin"		0.30		3, 9
7. Al-Mg-Si								
1	0.15	0.54	0.55	0.006		0.56		3
8. Al-Si								
1						5.0		3
2						8.0		3
3		0.30				8.5		3
4		0.45				11.04		3
5						12.65		3
6		0.5	(Ca,0.05;Na,0.006)			12.7		2, 8
7						13.0		3
8		0.35				13.75		3
9. Al-Zn								
1							5.21	2
2							9.26	2
3							11.0	2
4							16.85	2
5							26.0	2
10. Al-Zn-Cu					Sn			
1	3.04	1.23				0.29	7.73	3
2	2.07	0.62			0.05	0.27	11.4	3
3	2.17	0.73			0.06	0.30	12.1	3
4	3.0						15.9	3
5	2.5	0.20	0.5	0.5	"E" alloy	1.0	20.0	3, 9
6	2.9	0.20	"A" alloy			0.25	20.3	3, 9
7	3.0	0.20	"B" alloy			0.25	25.0	3

Comp. No.	% composition Cu	Al	Fe	Ni	Pb	Sn	Zn	Table
11. Cu, Electrolytic or Commercially Pure								
1	99.993		0.0052		<0.002			5
2	99.992		.0058		<0.002			5
3	99.991†		.008		<0.001			3
4	99.98		.02					3
5	99.96		Tr.	Tr.	Tr.			3
6	99.895							3

Comp. No.	% composition Cu	O	Fe	Ni	S		Table
12. Cu, Oxygenated							
1	99.954	0.036	0.002	0.0015	0.0002	These also	3
2	99.94	.049	.002	.0015	.0002	contain	3
3	99.90	.094	.002	.0015	.0001	0.001 Ag,	3
4	99.75	.240	.002	.0015	.0005	0.0015 As, 0.002 Sb	3

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

Comp. No.	% composition Cu	Al	Fe	Mn	Ni	Si	Zn	Table
13. Cu-Al, Al-Bronzes								
1	99.86	0.10						2
2	96.98	2.99	0.008			0.024		2
3	94.90	5.07	.006			.018		2
4	94.85	5.62	.065					3, 5
5	92.61	9.90	.017			.027		2
6	90.91	9.10	.002					3, 5
7	90.52	10.01	.002					3, 5
8	90.22	9.78						3
9	90.06	7.35	.017			.027		2
10	89.81	10.06						3
11	89.0	10.0	1.0					3
12	87.12	10.4	2.92					3, 5
14. Cu-Al-Mn								
1	89.06	10.2	0.01	0.92		0.01		2
2	88.30	9.82	.03	1.88		.34		2
3	88.11	8.91	.02	2.98		.02		2
15. Cu-Al-Ni								
1	87.45	7.91			4.64			2
2	87.45	6.93			5.62			2
3	87.32	5.34			7.34			2
16. Cu-Mn								
1	96.2		0.18	3.58				2

Comp. No.	% composition Cu	Fe	Mn	Ni	C	Sn	Zn	Table
17. Cu-Ni								
1	80.34	0.27	0.12	19.23	0.03			3
2	80.03	.16		19.43				3
3	78.92	.19	0.26	20.61		Cupro-nickel		3
4	53.77	.52	1.14	44.68	.11	Constantan		3, 5
5	53.71	.66	0.89	44.77	.078			3
18. Cu-Ni-Cr								
1	58.93	1.04	1.61	34.15	+(Cr, 4.14; Si, 0.13)			3, 5
19. Cu-Ni-Sn								
1	69.82	0.27		29.08	0.07	0.95		3
20. Cu-Ni-Zn								
1	74.01	0.34	0.75	19.75	0.07		5.17	3, 5
2	60.08	.20		10.89	German silver		29.05	3

Comp. No.	% composition Cu	Fe	Mn	P	Pb	Sn	Zn	Table
21. Cu-Sn, Bronzes								
1	96.12			0.32		3.54	Phos. bronze	2
2	95.74			.048		4.20		3
3	95.61	0.031		.056	0.002	4.66		5
4	95.57	.09		.39	<0.01	4.05	Phos. bronze	3
5	94.96					4.89		3
6	95.0			.026	0.01	5.06		3
7	89.39	.08		.13	<0.01	10.6	Phos. bronze	3
22. Cu-Zn, Brasses								
1	81.0	0.05			<0.01		19.06	3
2	73.28	.135			.026		26.61	3
3	72.36	.13	(S = 0.035%)		.13		27.46	2
4	71.69	.13			.017		28.24	5
5	70.08	.05			<0.01		29.99	3

Table 1.—Composition of Alloys.—(*Continued*)

Comp. No.	% composition Cu	Fe	Mn	P	Pb	Sn	Zn	Table
22. Cu-Zn, Brasses.—(*Continued*)								
6	69.85	0.04				Tr.	30.11	3
7	66.3	(Naval brass, α)			0.25	1.20	32.2	2
8	65.0						34.6	3
9	61.20	(Naval brass)			0.10	0.43	38.27	3
10	60.81	.002	(Naval brass)		.002	0.85	38.32	3
11	60.25	.02			.02		39.61	3
12	59.78	.03			.08		40.11	3
13	59.65	.164	(Muntz metal)		.20	0.10	40.11	3, 5
14	58.5	.87	(Naval brass, α, β)			0.50	40.1	2, 6
15	58.19	.65	(Mn bronze)		0.02	1.04	40.10	3
16	58.0	.80	(Muntz metal)			Tr.	41.2	2
17	56.85	1.50	0.20	(Mn bronze)		0.32	40.90	3
22.5. Cu-Zn-Pb, Leaded Brasses								
1	61.60	0.03			0.06		38.31	3
2	61.54	.04			0.53		37.89	3
3	61.03	.03			1.58		37.89	3
4	59.58	.03			2.61		37.78	3
5	59.40	.03			3.43		37.14	3

Comp. No.	% composition, Fe+ C		Mn	P	S	Si	Table
23. Fe, Commercially Pure							
1	0.012	Armco iron	0.07	0.014	0.017	0.017	2, 3, 5
2	.02	Ingot iron	.03	.005	.042	.02	2, 3, 4, 5
3	.023	Ingot iron	.037	.002	.031	.005	3
4	.029	Wrought iron	.07	.219	.024	.127	2
5	.039	Wrought iron	Tr.	.018		Tr.	2
6	.045	Wrought iron	0.024	.246	.017	0.234	2, 3
7	.06	Wrought iron	.12	.25	.023	.13	3
8	.195	Wrought iron	.005	.054	.011	.086	2

Comp. No.	% composition, Fe+ C	Cr	Mn	Ni	P	S	Si	Table
24. Fe-C, Carbon Steels								
1	0.065		0.04		0.135	0.010	0.148	2
2	.11	(Comp. Nos. 2, 11, and 14 are case-hardening steels)	.73	0.12	.02	.018	.10	3
3	.13		.70		.046	.042	.18	2, 3, 5
4	.13		.30		.028	.017	.028	2, 6
5	.14		.68		.045	.04	.19	3
6	.14		.53		.008	.056	.17	3
7	.15							2, 3
8	.15		.30		.018	.034	.06	3
9	.16							2
10	.17		.10		.013	.012	.021	2
11	.17		.46		.023	.032	.12	3
12	.18		.37		.013	.039	.06	3
13	.19		.60		.052	.047	.024	2
14	.19		.65		.025	.049	.05	3
15	.20		.67		.025	.090	.03	3
16	.20	0.06	.58	0.18	.044	.034	.18	3
17	.21	.017	.82	.206	.06	.08	.08	3
18	.24		.83		.033	.043	.33	2, 6
19	.24		.45		.009	.051	.007	3, 5
20	.25		.65		.05	.03	.06	2, 3, 5
21	.25		1.18		.031	.04	.25	3, 5
22	.26		0.54		.027	.031	.05	3
23	.27		.58		.055	.038	.065	2, 6

Table 1.—Composition of Alloys.—(*Continued*)

Comp. No.	% composition, Fe+ C	Cr	Mn	Ni	P	S	Si	Table
24. Fe-C, Carbon Steels.—(*Continued*)								
24	0.29		0.52		0.01	0.051	0.17	3
25	.29		.75		.057	.046	.037	2, 6
26	.30				.05	.04		3
27	.31		.47		.013	.03	.16	3
28	.31		.67		.04	.048	.14	3
29	.31		.86		.078	.091		3
30	.32		.58		.049	.052	.22	3
31	.33		.59		.049	.051	.22	2, 3, 5
32	.34		.68		.045	.023	.055	2, 6
33	.34		.56		.026	.021	.072	2
34	.35							2
35	.36		.66		.02	.041	.25	3
36	.37							2, 3
37	.37		.58		.032	.035	.16	2, 3, 4, 5
38	.38		.69		.025	.030	.066	2, 6
39	.38		.57		.033	.048	.04	3, 5
40	.40		.77			.029		4
41	.40				.05	.08		3
42	.41		.54		.017	.024	.14	5
43	.42		.62		.02	.03	.17	3
44	.44		1.05				.30	4
45	.446		0.47		.067	.044	.063	2
46	.45							2
47	.45		.54	0.12	.017	.016	.15	3
48	.46		.68	.13	.015	.021	.11	5, 7
49	.48		.60		.010	.038	.19	3
50	.49		.46		.017	.029	.12	2–5, 7, 9
51	.51		.59		.053	.038	.083	2, 6
52	.52		.56		.037	.029	.24	3, 4, 5
53	.53		.48		.017	.037	.12	2, 3
54	.57		.60		.058	.034	.121	2, 6
55	.60	0.09	.77	.03	.011	.007	.21	3
56	.60	(Comp. Nos. 55 and 68 are spring steels)	.69		.039	.04	.20	3
57	.62		.23		.011	.031	.186	2, 6
58	.63		.56		.055	.038	.111	2, 6
59	.645		.26		.028	.010	.062	2
60	.65		.11		.03	.020	.14	2, 3, 5, 8
61	.71		.72	.11	.029	.032	.44	3
62	.72		.26		.015	.032	.163	2, 6
63	.77	(Comp. Nos. 55 and 68 are spring steels)	.55		.037	.047	.18	3
64	.79		.30		.015	.032	.182	2, 6
65	.81		.32		.012	.031	.16	3, 5
66	.93		.38		.017	.045	.03	2, 3, 4, 5
67	.97		.31	.18	.019	.020	.13	3
68	1.02		.24		.012	.029	.145	3, 9
69	1.20		.25		.021	.021	.19	2–5, 7

Comp. No.	% composition, Fe+ C, graphite	C, combined	Mn	P	S	Si	Table
25. Fe-C, Cast Iron							
1	1.70	0.56	0.95	0.045	0.037	2.49	2, 8
2	1.97	.46	.27	1.48	.069	2.07	2
3	2.10	.47	.77	0.060	.029	2.30	2

Comp. No.	% composition, Fe+ Ce	C	Mn	Ni	P	S	Si	Table
26. Fe-Ce-C, Ce-Steels								
1	0.41–0.61	0.38	0.68				0.35	4

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

27. Fe-Cr-C, Cr-Steels

Stainless steels, excepting No. 1

Comp. No.	Cr	C	Mn	Ni	P	S	Si	Table
1	0.94	0.35	0.62				0.35	4
2	11.71	.085	.32	0.13	0.019	0.042	.594	2
3	11.78	.08	.07	Cu, 0.05	.017	.007	.11	3
4	12.33	.247	.36		.012	.075	.09	2, 3
5‡	12.26	.42	.27	0.20	.016	.058	.056	3, 5
6	12.9	.32	.30	.3	.026	.03	1.36	3
7	13.18	.09	.03	(Stainless iron)			0.06	3, 5
8	13.34	.08	.06	0.12	0.017	.003	.08	3
9	13.31	.21	.59	.13	.017	.017	.79	3
10	14.31	.104	.447	Tr.	.006	Tr.	.935	2
11‡	14.99	.85	.39	.26	.020	.005	.16	3, 5
12	15.21	.40	.28	.18	.017	.058	.59	3, 5
13‡	15.81	.61	.39	.24	.018	.035	.03	3, 5

28. Fe-Cr-Ce-C, Cr-Ce-Steels

Comp. No.	Cr	Ce	C	Mn	Ni	Si	Table
1	0.98	0.41–0.50	0.41	0.64		0.27	4

29. Fe-Cr-Mo-C, Cr-Mo-Steels

Comp. No.	Cr	Mo	C	Mn	P	S	Si	Table
1	0.55	0.39	0.42	0.55			0.19	4
2	.73	.28	.15	.36			.12	4
3	.76	.18	.39	.49	0.034	0.035	.195	3
4	.79	.34	.22	.59			.14	4
5	.85	.20	.31	.44	.034	.035	.22	3
6	.88	.30	.40	.65			.12	4
7	.89	.36	.41	.63			.28	4
8	.95	.10	.40	.52	.033	.024	.26	3
9	.95	.39	.52	.71			.16	4
10	.95	.68	.40	.62			.40	4
11	.95	.73	.25	.48			.19	4
12	1.03	.19	.50	.48	.030	.039	.24	3
13	1.04	.09	.42	.53	.032	.023	.25	3

30. Fe-Cr-V-C, Cr-V-Steels

Comp. No.	Cr	V	C	Mn	P	S	Si	Table
1	0.93	0.16	0.41	0.67	C. No.	Ni	0.13	4
2	.93	.20	.40	.64	5	0.20	.31	4
3	.95	.20	.44	.49	6	.173		3
4	.99	.19	.55		8	.19		3
5	1.00	.16	.45	.56	0.016	0.030	.13	3, 5
6	1.16	.23	.24	.30	.046	.044	.29	3
7	1.46	.23	.53	.50	.005	.038	.22	3
8	1.48	.33	.46	.64	.31	.28	.19	3
9	13.47	.27	.03		.04	.01		3

31. Fe-Mo-C, Mo-Steels

Comp. No.	Mo	C		Mn	P	S	Si	Table
1	0.34	0.44		1.29			0.33	4
2	.37	.38		0.71			.35	4
3	.67	.41		0.72			.42	4
4	.73	.43		1.24			.46	4
5	1.05	.46		0.75			.43	4
6	3.00	.36		0.65			.30	4

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

32. Fe-Ni-C, Ni-Steels

Comp. No.	Ni	C	Cr	Mn	P	S	Si	Table
1	2.93	0.38	0.23	0.62	0.032	0.03	0.19	2, 8
2	2.96	.39		.55	.031	.039	0.11	3
3	3.00	.41		.70			2.47	4
4	3.06	.39		.61	.024	.019	0.14	3, 5
5	3.12	.12		.30	.022	.022	.037	2, 6
6	3.25	.38		.28	.027	.024	.063	2, 6
7	3.35	.31		.64	.026	.028	.13	3, 5, 7
8	3.41	.41	0.18	.75	.02	.02	.25	2–7
9	3.56	.14		.50	.029	.021	.19	2, 6
10	3.60	.42		.70	.017	.016	.12	3, 5
11	3.70	.29		.66	.005	.046	.14	3
12	3.74	.28		.578	.014	.047	.195	5, 7
13	4.70	.50		.32	.023	.027	.233	2, 6
14	4.84	.14		.29	.009	.018	.16	3
15	5.10	.13		.16	.038	.038	.187	3
16	5.76	.11	0.10	.20	.033	.031	.18	3

Comp. Nos. 14–16 are case hardening steels.

33. Fe-Ni-Ce-C, Ni-Ce-Steels

Comp. No.	Ni	Ce	C	Mn	S	Si	Table
1	2.86	0.33 to 0.58	0.43	0.91		2.54	4

34. Fe-Ni-Cr-C, Ni-Cr-Steels

Comp. No.	Ni	Cr	C	Mn	P	S	Si	Table
1	0.47	1.10	0.43	0.63	0.012	0.038	0.22	3
2	1.23	0.65	.47	.64			.36	4
3	1.36	.65	.368	.681	.012	.013	.13	5, 7
4	1.41	.81	.46	.82	.015	.020		3
5	1.45	1.10	.41	.64	.009	.033	.20	3
6	1.75	0.99	.49		Nos. 10, 11 are case hard-			3
7	2.49	.83	.37	.63	ening steels		.28	4
8	2.56	.83	.36	.65			.33	4
9	2.93	.69						2
10	3.00	.48	.19	.45	0.021	0.028	.32	3
11	3.15	.58	.20	.39	.022	.033	.28	3
12	3.18	.96	.33	.47	.007	.052	.18	3
13	3.33	.84						2
14	3.33	.87	.24	.37	.019	.025	.15	3, 4, 5, 7
15	3.33	.18	.41	.65	.018	.025	.15	3, 9
16	3.45	.76	.32	.60	.03	.03	.12	3
17	3.48	.78	.32	.46			.23	3
18	3.6	.6	.30	.40	.02	.02	.17	2, 6
19¶	4.30	1.40	.30	.56	.015	.041	.22	3
20	4.65	0.29	.16	.43	.033	.044	.11	3
21	19.70	8.31	.33	.49	Stainless steel "Cyclops metal"		1.16	3, 5, 9

35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)

Comp. No.	Ni	Cr	C	Cu	Mn	P	S	Si	Table
1	12.19	19.01	0.80	0.05	0.86	0.017	0.045	1.70	3
2	15.88	15.95	.38	.08	.71	.020	.048	2.36	3
3	22.90	5.42	.24	.78	.80	.010	.027	1.65	3, 5
4	25.27	17.71	.39	.12	.66	.018	.030	1.44	3
5	25.81	17.32	.70	.05	.72	.018	.060	3.08	3
6	28.20	8.38	.45	.67	.49	.012	.022	1.39	3, 5

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

Comp. No.	Ni	Cr	Ce	C	Mn	P	S	Si	Table
	% composition, Fe+								
36. Fe-Ni-Cr-Ce-C, Ni-Cr-Ce-Steels									
1	1.02	0.84	0.12	0.54	0.84			0.48	4
2	1.17	.77	.25	.41	.63			.33	4
3	2.46	.92	.19	.36	.66			.34	4
4	2.47	.95	.24	.43	.58			.35	4

Comp. No.	Ni	Cr	Mo	C	Mn	P	S	Si	Table
	% composition, Fe+								
37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels									
1	1.27	0.67	0.83	0.41	0.64			0.41	4
2	1.28	.68	.31	.39	.66			.27	4
3	2.39	.86	.75	.50	.63			.44	4
4	2.44	.82	.37	.44	.66			.43	4
5	2.45	.88	.35	.46	.61			.32	4
6	2.49	.79	.76	.41	.60			.31	4
7	2.52	.83	.34	.53	.65			.36	4
8	2.53	.78	.75	.38	.61			.48	4
9	4.83	.96	.89	.27	.35	0.015	0.02	.13	3

Comp. No.	Ni	Cr	V	C	Mn	P	S	Si	Table
	% composition, Fe+								
38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels									
1	1.20	0.75	0.24	0.39	0.71			0.28	4
2	2.52	.84	.20	.40	.61			.28	4
3	3.30	.60	.10	.30		0.034	0.022	.31	2, 3

Comp. No.	Ni	Mo		C	Mn	P	S	Si	Table
	% composition, Fe+								
39. Fe-Ni-Mo-C, Ni-Mo-Steels									
1	1.70	0.12		0.41	0.46	0.037	0.020	0.22	3
2	2.95	.70		.37	.52			2.50	4

Comp. No.	Ni	V		C	Mn	P	S	Si	Table
	% composition, Fe+								
40. Fe-Ni-V-C, Ni-V-Steels									
1	2.94	0.12		0.36	0.51			2.42	4

Comp. No.	Ni	Zr		C	Mn	P	S	Si	Table
	% composition, Fe+								
41. Fe-Ni-Zr-C, Ni-Zr-Steels									
1	3.00	0.24		0.43	0.57			2.40	4

Comp. No.	Si	Mn	C		P	S	Table
	% composition, Fe+						
42. Fe-Si-Mn-C, Si-Mn-Steels							
1	1.97	0.65	0.55	(Spring steel)	0.024	0.037	3

Comp. No.	V	Cr	C	Mn	P	S	Si	Table
	% composition, Fe+							
43. Fe-V-C, V-Steels								
1	0.16	0.12	0.57	0.74	0.04	0.03		3
2	.16		.504	.79	.017	.031	0.23	5, 7
3	.20		.50	.84			.16	4

Comp. No.	Mg	Al	Cu	Zn	Fe	Mn	Si	Table
	% composition							
44. Mg, Commercial								
1	99.96				0.02		0.02	3
2	99.89	Tr.	0.02		0.03		0.06	3

TABLE 1.—COMPOSITION OF ALLOYS.—(*Continued*)

Comp. No.	Mg	Al	Cu	Zn	Fe	Mn	Si	Table
	% composition							
45. Mg-Al								
1	95.77	4.20			0.03			3
2	95.31	4.40			.03	0.26		3
3	94.0	6.0						3
4	93.26	6.70			.04			3
5	92.90	6.80			.04	0.26		3
6	91.23	8.68	0.026		.041		0.023	3
46. Mg-Cu								
1	90.31		9.65		0.04			3
47. Mg-Zn								
1§	94.72	Tr.	0.41	4.38	0.25		0.24	3

Comp. No.	Ni	Cu	Fe	Mn	C	S	Si	Table
	% composition							
48. Ni, Commercial								
1	99.32		0.32		0.15	0.016	0.023	2, 3
2	99.07	0.159	.59	0.184	.044	.025	.008	3, 5
3	99+							3
4	98.95	.12	.50	.10	.25	.175	.06	3, 5
5	98.70	.23	.74	.16	.099	.16	.06	3
49. Ni-Cr								
1	79.7	0.13	0.88		0.09	0.012	0.10	2, 8
		+Cr, 19.04; Mg, 0.05						
50. Ni-Cu								
1	76.66	21.28	1.40	0.26	0.26	0.006	0.065	3
2	72.91	23.56	1.73	1.94	.216	.007	.075	3
3	69.08	28.07	1.56	1.01	.18	.005	.02	3
4	68.95	27.29	2.22	1.38	.20	.019	.08	3, 5
5	67.74	28.64	1.75	1.62	.21	.019	.01	3
6	66.81	29.65	1.53	1.79	.18	.015	.02	3
7	66.78	29.54	2.10	1.44	.16	.039	.02	3, 5
8	66.0	30.0	2.10	1.30	.19	.03		3
9	65.28	30.53	2.12	1.53		.027	.14	2
10	55.23	44.18	0.44	0.36	.016	.009	.002	3

4 has trace Al; 1 has 0.023 P; 4 has 0.19 P; 5 has 0.014 P; 7 has 0.019 P; 8 has 0.04 P; 10 has 0.006 P. 1–7 are Monel metals.

Comp. No.	Ni	Cu	Fe	Mn	C	S	Si	Table
51. Ni-Cu-Mn								
1	68.74	28.16	0.56	2.35	0.10	0.008	Tr.	2, 8
2‖	67.51	26.23	1.39	4.31	0.20	0.028	0.40	3

* The mechanical properties depend to some extent on the relative positions of the specimen and crystallographic axes.

† By difference.

‡ 5 has 0.04 Cu, 11 has 0.03 Cu, 13 has 1.10 Cu.

¶ Air hardening steel.

§ Electron metal.

‖ Contains 0.024 P.

TABLE 2.—ENDURANCE LIMITS UNDER REVERSED DIRECT STRESSES

Key No.*	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$†	Endurance limit, kg/mm²-FL_7 [Def. 17(b)]	Endurance limit / Tensile strength	Lit.
1. Al						
2	A, single crystal§	Al, 99.6	6 H‡	2.52§	0.38	(9.5)
8. Al-Si						
6A	G_mM	Si, 12.7	10 H‡	6.0	0.27	(22)
B	G_mM, 250°/180 C_a		10 H‡	4.7	0.24	(22)
C	G_sM		10 H‡	7.1	0.36	(22)

TABLE 2.—ENDURANCE LIMITS UNDER REVERSED DIRECT STRESSES.—(*Continued*)

Key No.*	Treatment	Approximate composition	$10^{-6}n$	FL_0	$\frac{FL_0}{UTS}$	Lit.
		9. Al-Zn				
1	R_h	Zn, 5	1	3.9	0.28	(23)
2	R_h	9	1	5.3	.32	(23)
3	R_h	11	1	6.8	.37	(23)
4	R_h	17	1	7.9	.28	(23)
5	R_h	26	1	9.4	.24	(23)
		13. Cu-Al, Al-Bronzes				
1	R_h	Al, 0.1	1	7.3	0.32	(4)
2	R_h	3.0	1	13.4	.43	(4)
3	R_h	5.1	1	16.2	.39	(4)
5	R_h	9.9	1	16.2	.35	(4)
9	R_h	10.0	1	22.3	.37	(4)
		14. Cu-Al-Mn				
1	R_h	Al, 10; Mn, 1	1	19.5	0.29	(24)
2	R_h	Al, 10; Mn, 2	1	19.5	.30	(24)
3	R_h	Al, 9; Mn, 3	1	19.5	.31	(24)
		15. Cu-Al-Ni				
1A	900° Q_w	Al, 7.9; Ni, 4.6	H‡	17.7		(2)
B	900° Q_w 700°/30 C_a		H‡	19.7		
2A	900° Q_w	Al, 6.9; Ni, 5.6	H‡	16.9		(2)
B	900° C_s (900–700° in 200 m)		H‡	20.4		
3	900° Q_w 700°/30 C_a	Ni, 7.3; Al, 5.3	H‡	23.2		(2)
		16. Cu-Mn				
1	A	Mn, 3.6	10 H‡	11.8	0.42	(27)
		21. Cu-Sn, Bronzes				
1	As received, R (P-bronze)	Sn, 3.5; P, 0.032	10 H‡	19.2	0.47	(27)
		22. Cu-Zn, Brasses				
3	As received, R	Zn, 27.5	10 H‡	13.2	0.35	(27)
7	As received, R (naval brass, α)	32.2	2 H‡	13.8	.38	(12)
14A	As received (naval brass, αβ)	Zn, 40.1	2 H‡	18.9	.42	(12)
B	A		2 H‡	18.5	.45	(12)
16A	As received (Muntz metal)	Zn, 41.2	2 H‡	19.7	.38	(12)
B	A		2 H‡	17.3	.42	(12)
		23. Fe, Commercially Pure				
1A	A 1000°/30 C_f } Armco iron	Fe, 99.87; C, 0.012	10 H‡	15.6	0.53	(9)
B	N 950° } Armco iron		10 H‡	18.7	.54	(27)
2A	As received, A_b (ingot iron)	Fe, 99.88; C, 0.02	10	11.9	.40	(20)
4	As received } Wrought iron	C, 0.03	2	17.0	.45	(26)
5	A } Wrought iron	.04	H‡	15.2	.50	(12)
6	F } Wrought iron	.05	10	11.2	.34	(20)
8	As received } Wrought iron	.195	2	15.1	.37	(26)
		24. Fe-C, Carbon Steels				
1	As received	C, 0.07	2	14.9	0.43	(26)
3	N 850°	C, 0.13	10 H‡	21.7	.45	(9)
4	R_h	.13	8 H‡	20.5	.51	(12)
7	A	.15	H‡	17.2	.50	(29)
9	As received, R	.16	10 H‡	19.7	.44	(27)
10	As received, R	.17	2	21.1	.46	(26)
13A	As received, R_h	C, 0.19	1	18.5	.41	(25)
B	R_h A 900°	.19	1	17.1	.40	
18A	As received	C, 0.24	1	22.7	.38	(25)
B	A	.24	1	20.7	.36	
20	As received, R	C, 0.25	8 H‡	19.4	.42	(9)
23	As received, R	.27	1	21.2	.41	(25)
25	As received, R	.29	1	21.6	.40	(25)
31	850°/15 C_a	.33	10 H‡	22.1	.27	(11)
32	As received	C, 0.34	1	22.8	.39	(25)
33	F	.34	2	16.2	.35	(26)
34	As received	.35	3 H‡	27.5	.41	(12)
36	A	.37	H‡	23.2	.41	(29)
37A	As received	C, 0.37	10	17.6	.34	(20)
B	810°/15 C_{fo}	.37	10	14.8	.29	
C	845°/15 Q_w, 570° C_a (sorbitic)	.37	10	23.2	.32	
		24. Fe-C, Carbon Steels.—(*Continued*)				
38	As received, R	C, 0.38	1	23.3	0.38	(25)
45	As received	.44	2	22.4	.32	(26)
46	As received	.45	10 H‡	23.3	.35	(27)
50B	925°/20 C_a	C, 0.49	10	14.1	.22	(20)
51	As received	.51		20.3	.29	(25)
53A	925°/20 C_a	.53	10	16.9		(20)
54	As received	C, 0.57	1	26.8	.36	(25)
57	As received	.62	1	22.4	.31	(25)
58	As received	.63	1	28.0	.39	(25)
59	As received	C, 0.64	2	24.9	.33	(26)
60	N 800°	.65	10 H‡	30.2	.38	(9)
62	As received	.72	1	21.2	.24	(25)
64	As received	.79	1	23.6	.38	(25)
66	As received	.93	10	24.6	.26	(20)
69	795°/15 C_f, 860°/15 C_{fo}	1.20	10	19.3	.24	(20)
		25. Fe-C, Cast Irons				
1	As cast	Graphite 1.70; Comb. C 0.56	6 H‡	15.0	0.43	(12)
2	As cast	Graphite 1.97; Comb. C .46	6 H‡	7.9	.47	(12)
3	As cast	Graphite 2.10; Comb. C .47	8 H‡	12.9	.41	(12)
		27. Fe-Cr-C, Cr-Steels (Stainless Steels)				
2	N	Cr, 11.7; C, 0.09	10 H‡	32.0	0.53	(27)
4	As received	Cr, 12.3; C, 0.25	10 H‡	36.2	.46	(22)
10	As received, R	Cr, 14.3; C, 0.1	10 H‡	32.4	.53	(27)
		32. Fe-Ni-C, Ni-Steels				
1	As received	Ni, 2.93; C, 0.37	10 H‡	31.2	0.43	(27)
5	As received, R	Ni, 3.12; C, 0.12	1	22.8	.50	(25)
6	As received, R	Ni, 3.25; C, 0.38	1	30.9	.61	(25)
8A	830°/30 C_f. 590°/120 C_f	Ni, 3.41; C, 0.41	10	31.0	.36	(20)
B	830°/15 Q_o 650°/120 C_f		10	26.0	.31	
C	830°/30/C_f, 810°/15 Q_w (500°); S_h W_s 590°/60 C_f		10	29.6	.36	(20)
D	785°/60 C_f		10	25.7	.36	(25)
9A	As received, R	Ni, 3.56; C, 0.14	1	27.0	.54	(26)
B	A 750°		1	26.5	.54	(25)
13	As received, R	Ni, 4.70; C, 0.50	2	29.8	.47	(25)
		34. Fe-Ni-Cr-C, Ni-Cr-Steels				
9	Not stated	Ni, 2.93; Cr, 0.68; C (-)	8 H‡	39.6	0.42	(29)
13	Not stated	Ni, 3.33; Cr, 0.84; C (-)	8 H‡	40.9	.49	(29)
18	Not stated	Ni, 3.6; Cr, 0.6; C, 0.3	8 H‡	36.2	.45	(15)
		38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels				
3	"Spec. S2 British Air Ministry"	Ni, 3.3; Cr, 0.6; V, 0.1; C, 0.3	10 H‡	42.8	0.45	(22)
		48. Ni, Commercial				
1	R_h	Ni, 99.32	3 H‡	20.5	0.40	(13)
		49. Ni-Cr				
1	R_h	Cr, 19.04	10 H‡	23.6	0.29	(27)
		50. Ni-Cu				
9	As received, R	Cu, 30.5	10 H‡	21.2	0.38	(27)
		51. Ni-Cu-Mn				
1	As received, R	Cu, 28; Mn, 2.4	10 H‡	25.1	0.40	(22)

* The key number is the same as the composition number where data are given for only one condition or treatment; while if data are given for more than one, the letters A, B, C, . . . are added to the composition numbers to distinguish the different treatments given.

† The number given in this column denotes the maximum number of millions of reversals of stress for which the fatigue stress was investigated. It does not denote the number of reversals at which the curve Fatigue Strength *vs.* Number of Reversals becomes parallel to N axis, although in many cases this has occurred at a smaller number of reversals.

‡ The H in column 4 denotes results obtained on the Haigh electromagnetic machine; in other cases the stresses are produced by inertia of unbalanced rotating weights or by calibrated springs.

§ Values will depend to some extent on the relative positions of the specimen and crystallographic axis.

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES)*

Key No.†	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$†	Endurance limit, kg/mm², FL_0 [Def. 17(b)]*	Endurance limit / Tensile strength	Lit.
	1. Al					
1	R	Al, 99.24	170	7.4	0.47	(19)
	2. Al-Cu					
1	700° G_s	Cu, 2.0	40	3.5	0.21	(17)
2	Tp	Cu, 4.6	100	11.3	.27	(16)
3	700° G_s	Cu, 8.0	100	4.2	.31	(17)
4	G_m	Cu, 12.0	7	4.2	.21	(15)
5	G_s	Cu, 12.6	15	5.1	.42?	(15)
	3. Al-Cu-Mg-Si					
1A	505°/7.5Q_b	Cu, 3.25; Mg, 0.7	400	9.8	0.27	(19)
B	Same, Tp 495°/30 Q_b (2 h)		400	8.4	.23	
C	Same, Tp 370°/20 C_f		200	7.7	.43	
2	F, W 500°/60 (niter) Q_w 150°/60 (oil) C_a	Cu, 3.6; Mg, 0.7	100	10.6	.31	(7)
3	F	Cu, 3.75; Mg, 0.26	10	8.5	.31	(7)
4	F, 500°/60 Q_w, 100°/6 d	Cu, 3.88; Mg, 0.78	10	14.0	.38	(7)
5	R_h,‡ 480°/Q_w, V	Cu, 4.0; Mg, 0.50	2	16.6	.41	(13)
6	As received	Cu, 4.18; Mg, 0.66	12	14.9	.32	(14)
7	Tp, "duralumin"	Cu, 4.3; Mg, 0.42	200	12.0	.28	(16)
8	R_h,‡ 480° Q_w, V	Cu, 5.0; Mg, 0.75	3	16.6	.40	(13)
9	R_h,‡ 480° Q_w, V	Cu, 6.0; Mg, 0.75	3	16.1	.36	(13)
	4. Al-Cu-Ni-Mg					
1	R_h,‡ "magnalite"	Cu, 2; Ni, 1.5; Mg, 1	4	14.2		(13)
2	R_h, 480° Q_w	Cu, 4; Ni, 1; Mg, 1	10	15.5	0.43	(22)
3	R_h, 480° Q_w	Cu, 4; Ni, 1; Mg, 1.5	10	16.0	.45	(22)
4	R_h,‡ 480° Q_b, V	Cu, 4; Ni, 2; Mg, 1.5 "Y" alloy	3	14.2	.40	(13)
5	R_h,‡ 480° Q_b, V		3	16.3	.45	(13)
6	R_h,‡ 520° Q_b, V		10	16.0	.41	(13)
7	520°/360 Q_b, V 5 d		20	11.0	.35	(9)
	5. Al-Cu-Zn					
1	G_m	Cu, 8.7; Zn, 5.3	6	7.1	0.37	(15)
2	G_s	Cu, 9.5; Zn, 5.5	6	3.7	.26	(15)
	6. Al-Mg					
1	R_h,‡ ("aeromin")	Mg, 6.2	3	10.3	0.30	(13)
	7. Al-Mg-Si					
1	Tp	Mg, 0.55; Si, 0.56	50	8.5	0.28	(16)
	8. Al-Si					
1	G_s	Si, 5.0	50	4.2	0.32	(3)
2	G_sM	Si, 8.0	50	5.6	.35	(3)
3	G_mM	Si, 8 5	10	6.6	.34	(22)
4	G_mM	Si, 11.0	10	6.7	.31	(22)
5	G_sM	Si, 12.7	10	5.0	.29	(22)
7	G_sM	Si, 13.0	50	5.8	.33	(3)
8	G_mM	Si, 13.8	10	7.7	.42	(22)
	10. Al-Zn-Cu					
1	705° G_s	Zn, 7.7; Cu, 3	10	6.0	0.29	(7)
2	G_s	Zn, 11.4; Cu, 2	8	3.7	.19	(15)
3	G_m	Zn, 12.1; Cu, 2	8	4.7	.23	(15)
4	G_s	Zn, 16.9; Cu, 3	70	4.1	.17	(17)
5	R_h,‡ 350°/Q, V ("E" alloy)	Zn, 20; Cu, 2.5	2	15.3	.26	(13)
6	R_h‡ ("A" alloy)	Zn, 20.3; Cu, 3	2	13.7	.33	(13)
7	R_h‡ ("B" alloy)	Zn, 25; Cu, 3	2	16.5	.35	(13)
	11. Cu, Electrolytic or Commercially Pure					
3A	As received	Cu, 99.99	100	11.3	0.31	(16)
B	R_oW 650°/60 C_f		100	7.4	.33	
4A	As received, D_o	Cu, 99.98	68	8.8	.31	(16)
B	D_o 650°/60 C_f		C§	6.7	.31	
5	A	Cu, 99.96	30	8.2	.36	(9)
6A	E W 520°/30 C_f	Cu, 99.90	100	7.1	.31	(20)
B	E W 700°/30 P_w		400	7.0	.31	
C	E W 700°/30 P_w D_o (0.5 in. diam.)		300	7.0	.18	

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES).*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_c}{UTS}$	Lit.
	12. Cu, Oxygenated					
1	R_h, D (4 stages) intermediate anneals at 600°C	0.04% O	50	12.9	0.49	(8)
2		.05	50	12.3	.47	(8)
3		.09	50	13.0	.49	(8)
4		.24	50	11.6	.41	(8)
	13. Cu-Al, Al-Bronzes					
4A	As received, R	Al, 5.6	70	13.4	0.26	(16)
B	R, 650°/60 C_f		C§	10.7	.26	
6A	As received, R	Al, 9.1	70	17.2	.28	(16)
B	R, 705°/60 C_f		C§	12.9	.28	
7A	As received, R	Al, 10.0	50	20.7	.35	(16)
B	R, 650°/60 C_a		50	14.1	.32	
8A	G	Al, 9.8	60	15.5	.37	(19)
B	G, 900° Q_w 650°/30 C_f		70	18.3	.34	
10	E W 900° Q_w 620°/30 C_f	Al, 10.1	60	23.9	.44	(19)
11A	G_s	Al, 10.0	10	19.0	.35	(5)
B	G_s, Q 850°, Tp 630°		10	23.2	.37	
12A	As received, R	Al, 10.4	60	24.6	.35	(16)
B	R, 650°/60 C_f		C§	22.1	.35	
	17. Cu-Ni					
1A	R_o	Ni, 19.2	50	12.7	0.36	(16)
B	R_o, 760°/60 C_f		C§	11.2	.36	
2	As received, R	Ni, 19.4	75	16.2	.34	(20)
3	As received ("cupro-nickel")	Ni, 20.6	40	16.4	.46	(9)
4A	As received, R_h	Ni, 44.7	50	24.3	.49	(16)
B	785°/60 C_f ("constantan")		C§	24.3	.49	
5A	As received R_o	Ni, 44.8	40	30.3	.42	(16)
B	As received R_o, 790°/60 C_f		10	19.7	.40	
	18. Cu-Ni-Cr					
1A	As received, F	Ni, 34; Cr, 4	50	23.9	0.35	(16)
B	815°/60 C_f		C§	24.6	.35	
	19. Cu-Ni-Sn					
1A	As received, D_o	Ni, 29; Sn, 1	50	23.6	0.38	(16)
B	815°/60 C_f		C§	15.8	.38	
	20. Cu-Ni-Zn					
1A	As received, R_h	Ni, 20; Zn, 5	30	16.2	0.40	(16)
B	760°/60 C_f		C§	14.6	.40	
2	As received, D_o ("German silver")	Ni, 11; Zn, 29	60	12.0	.29	(16)
	21. Cu-Sn, Bronzes					
2	As received, R(P-bronze)	Sn, 4.2	50	20.4	0.44	(16)
4A	As received R_o	Sn, 4	30	15.9	.40	(16)
B	As received R_o 650°/60 C_f		30	15.9	.47	(16)
5A	P_w, D (¼ in. diam.) 700°/30 P_w, D (⅛ in. diam.) 700°/30 P_w	Sn, 4.9	1000	16.2	.50	(20)
B	Same, D_o, 1 in. diam.		400	19.0	.32	
6A	As received, D_o	Sn, 5.1	70	19.0	.43	(16)
B	650°/60 C_f		C§	14.6	.43	
7A	As received R_o	Sn, 10.6	30	19.0	.33	(16)
B	As received R_o, 590°/60 C_f		30	19.0	.40	
	22. Cu-Zn, Brasses					
1A	As received D_o	Zn, 19	100	16.2	0.29	
B	As received D_o 235°/60 C_f		100	18.3	.32	(16)
C	As received D_o 540°/60 C_f		100	12.3	.40	
2A	As received, D_o	Zn, 26.6	20	12.0	.34	(16)
B	650°/60 C_f		C§	11.1	.34	
5A	As received R_o	Zn, 30	100	12.3	.24	(16)
B	As received R_o 230°/90 C_f		100	14.1	.27	
C	As received R_o 235°/90 C_f		100	14.1	.27	
D	As received R_o 260°/90 C_f		100	15.2	.29	
E	As received R_o 650°/90 C_f		100	22.1	.33	
6	A	Zn, 30.1	60	14.2	.45	(9)
8	As received, R_o	Zn, 34.6	12	16.5	.43	(14)
9	R Naval brass	Zn, 38.27	600	14.8	.31	(19)
10	R_h Naval brass	Zn, 38.3	60	13.0	.31	(16)
11	G, W 780°, E 700° (1 in.) W 550°/30 P_w, D (½ in.) W 550°/30 P_w	Zn, 39 6	400	20.4	.41	(20)

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES).*—(Continued)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_0}{UTS}$	Lit.
	22. Cu-Zn, Brasses.—(*Continued*)					
12A	G, W 780°, E 700° (1 in.), 550°/30 P_w D, ¾ in.	Zn, 40.1	500	15.5	0.41	(20)
B	G, W 780°, E 700° (1 in.), 550°/30 P_w D_c, ½ in.		500	18.3	.27	
13A	Q_i Tp 250° Muntz metal	Zn, 40.1	60	11.3	.21	(16)
B	Q_i Tp 344° Muntz metal		100	13.0	.23	
C	Q_i Tp 425° Muntz metal		100	12.7	.27	
15A	As received, R_h (Mn bronze)	Zn, 40.1	70	13.0	.24	(16)
B	650°/60 C_f, (Mn bronze)		C§	11.6	.24	
17	960° G (Mn bronze)	Zn, 40.9	150	12.0	.24	(19)
	22.5. Cu-Zn-Pb, Leaded Brasses					
1	D_d	Zn, 38.3; Pb, 0.06	50	14.4	0.35	(8)
2	D_d	Zn, 37.9; Pb, 0.53	50	16.2	.40	(8)
3	D_d	Zn, 37.9; Pb, 1.58	50	16.2	.40	(8)
4	D_d	Zn, 37.8; Pb, 2.61	50	15.1	.37	(8)
5	D_d	Zn, 37.1; Pb, 3.43	50	13.7	.34	(8)
	23. Fe, Commercially Pure					
1A	A 1000°/30 C_f (Armco iron)	C, 0.012	100	19.8	0.67	(9)
2A	As received, A_b (Ingot iron)	C, 0.02	100	18.3	.61	(20)
B	A_b, W815°/15Q_w (Ingot iron)		100	23.2	.66	
3A	R_h (Ingot iron)	C, 0.023	100	16.5	.53	(16)
B	900°/60 Q_w (Ingot iron)		10	17.6	.54	
6	F (Wrought iron)	C, 0.045	100	16.2	.49	(20)
7	As received (Wrought iron)	C, 0.06	12	18.4	.51	(14)
	24. Fe-C, Carbon Steels					
2A	N 900°	C, 0.11	10	18.4	0.44	(14)
B	N 900°, W 760° Q_w		10	27.8	.58	
3	N 850°	C, 0.13	250	25.7	.53	(9)
5A	R_h 890° Q_o	C, 0.14	10	34.4	.45	(15)
B	Same, Tp 200°		10	33.6	.44	
C	Same, Tp 300°		10	32.7	.45	
D	Same, Tp 400°		10	29.6	.44	
E	Same, Tp 500°		10	29.6	.45	
F	Same, Tp 600°		10	25.4	.43	
6	As received	C, 0.14	100	17.4	.43	(16)
7	A	.15		18.0	.52	(29)
8	N 900°	.15	10	18.4	.55	(14)
11	R 900°, H 770°	C, 0.17	12	29.4	.47	(9)
12	R_h	.18	100	19.7	.46	(21)
14	R 880°, H 770°	.19	12	28.0	.46	(9)
15A	As received, D_c	C, 0.20	100	28.8	.47	(21)
B	D_c, 845°/15 C_f		100	17.6	.43	
C	D_c, 700°/15 C_f		100	20.4	.51	
16	As received	C, 0.20	12	22.1	.45	(14)
17	R_h	C, 0.21	100	23.4	.47	(16)
19A	As received	C, 0.24	10	17.9	.42	(16)
B	870°/30 C_f (*v. also* Figs. 1 and 2)		10	15.8	.41	
C	870°/30 C_a		10	17.2	.40	
D	870°/30 Q_o, 700°/30 C_f		10	17.9	.42	
E	870°/30 Q_o, 590°/30 C_f		10	17.9	.39	
F	870°/30 Q_o, 480°/30 C_f		10	20.7	.44	
G	870°/30 Q_o, 370°/30 C_f		10	19.3	.40	
H	900°/60 Q_w, 670°/60 C_f		10	21.4	.46	
J	900°/60 Q_w, 540°/60 C_f		10	22.2	.40	
K	900°/60 Q_w, 430°/60 C_f		10	20.7	.37	
20	As received, R	C, 0.25	12	19.5	.43	(9)
21	F	C, 0.25	10	25.0	.47	(16)
22A	D_c	C, 0.26	12	30.1	.47	(1)
22B	D_c, B 250°	C, 0.26	12	29.0	.46	(1)
C	D_c, B 400°		12	29.9	.48	
D	D_c, B 550°		12	28.4	.49	
24	A 650°	C, 0.29	100	21.1	.43	(16)
26	As received, R_h	.30	12	26.3	.45	(9)
27	830°/Q_o, A 650°	.31	100	21.1	.42	(16)
28	N 850°	.31	12	20.2	.36	(14)
29	As received, R_h	.31	12	33.9	.51	(9)
	24. Fe-C, Carbon Steels.—(*Continued*)					
30A	R_h 870° Q_w	C, 0.32	10	58.5	0.41	(15)
B	Same, Tp 200°		10	41.4	.43	
C	Same, Tp 300°		10	39.9	.46	
D	Same, Tp 400°		10	45.5	.44	
E	Same, Tp 500°		10	42.1	.42	
F	Same, Tp 600°		10	39.3	.50	
31	850°/15 C_a	C, 0.33	250	27.6	.47	(11)
35A	N 850°	C, 0.36	12	26.8	.45	(9)
B	850°/Q_o, Tp 600°		12	29.9	.41	
36	A	C, 0.37		21.1	.37	(29)
37B	810°/15 C_{fo}	C, 0.37	100	23.2	.46	(20)
C	845°/15 Q_w, 570° C_a (sorbitic)		100	40.1	.56	
39A	845°/30 C_f (*v. also* Figs. 1 and 2)	C, 0.38	10	21.4	.44	(20)
B	845°/30 C_a		10	22.5	.41	
C	930°/120 Q_o, 845°/30 C_f		10	20.7	.41	
D	845°/30 Q_o, 670°/30 C_f		10	23.6	.42	
E	845°/30 Q_o, 540°/30 C_f		10	23.6	.39	
F	845°/30 Q_o, 430°/30 C_f		10	23.6	.37	
G	980°/300 Q_o, 845°/60 C_f		10	20.7	.42	
H	845°/60 Q_w, 670°/60 C_f		10	25.0	.43	
J	845°/60 Q_w, 590°/60 C_f		10	27.8	.46	
K	845°/60 Q_w, 540°/60 C_f		10	29.2	.43	
L	845°/60 Q_w, 430°/60 C_f		10	27.1	.40	
41	As received	C, 0.40	12	29.1	.46	(9)
43	As received	.42	12	27.3	.42	(9)
47A	N	C, 0.45	12	28.8	.44	(9)
B	H_o 850°, Tp_o 600°		12	34.9	.46	
49	A 870°	.48	100	24.6	.43	(16)
50A	815°/30 C_a	C, 0.49	100	22.5	.42	(20)
B	925°/20 C_a		100	23.2	.36	
C	925°/20 C_a, 775° Q_w, 650° C_f		100	33.8	.50	
D	925°/20 C_a, 790°/15 Q_o		100	45.7	.51	
E	Same, Tp 760°/30 C_a		100	26.0	.43	
F	Same, Tp 650°/30 C_a		100	35.2	.53	
G	Same, Tp 540°/30 C_a		100	40.0	.53	
H	Same, Tp 430°/30 C_a		100	45.0	.53	
J	Same, Tp 315°/30 C_a		100	47.8	.54	
52A	845°/15 C_a	C, 0.52	100	29.5	.42	(20)
B	Same, 790°/15 Q_w, 650° C_a		100	38.7	.49	
53B	925°/20 C_a, 790°/15 Q_o, 760°/30 C_a	C, 0.53	100	27.4	.44	(20)
C	925°/20 C_a, 790°/15 Q_o, 650°/30 C_a		100	37.3	.56	
D	925°/20 C_a, 790°/15 Q_o, 540°/30 C_a		100	41.5	.53	
E	925°/20 C_a, 790°/15 Q_o, 425°/30 C_a		100	45.7	.50	
F	925°/20 C_a, 790°/15 Q_o, 315°/30 C_a		100	47.1	.52	
G	925°/20 C_a, 790°/15 Q_o, 205°/30 C_a		100	47.8	.51	
H	925°/20 C_a, 790°/15 Q_o		100	47.1	.52	
55A	Q_o, Tp 400°	C, 0.60	10	74.0	.43	(22)
B	Q_o, Tp 450°		10	65.4	.46	
C	Q_o, Tp 500°		10	59.7	.48	
D	Q_o, Tp 550°		10	59.2	.50	
56	N 810°	C, 0.60	10	28.4	.37	(14)
60	N 800°	C, 0.65	12	32.3	.41	(9)
61	Not stated	.71	10	30.2	.34	(14)
63	A 730°	.77	100	27.4	.35	(16)
65A	790°/30 C_f	C, 0.81	10	22.2	.35	(16)
B	800°/120 C_a		10	27.1	.35	
66B	870°/15C_a, 790°/15C_f	C, 0.93	100	31.4	.38	(20)
C	870°/15C_a, 790°/15Q_o, 650°/30C_a		100	39.4	.40	
D	870°/15C_a, 790°/15Q_o, 455°/30C_a		100	68.9	[illegible]	
67	790°/60 C_f	C, 0.97	10	22.9	.37	[illegible]
68	790°/30 C_f, 790°/30 Q_o	C, 1.02	10	73.9		[illegible]
69A	795°/15 C_f, 860°/15 C_{fo}	C, 1.20	100	35.2	[illegible]	[illegible]
B	795°/15 C_f, 800° Q_o, 460°/15 C_a		100	64.7	[illegible]	

Table 3.—Endurance Limits Under Reversed Bending Stresses (Rotating Beam Machines).*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_0}{UTS}$	Lit.
		24. Fe-C, Carbon Steels.—(*Continued*)				
69C	795°/20 C_f, 885°/15 Q_o.....	(*v. also* Figs. 1 and 2)	100	73.9	0.48	(20)
D	205°/30 C_a......		100	75.2	.48	
E	345°/30 C_a		100	76.0	.48	
F	Same, Tp { 495°/30 C_a......		100	71.7	.47	
G	650°/30 C_a......		100	47.8	.49	
H	760°/30 C_a......		100	37.6	.45	
J	795°/15 C_f, 770°/30 Q_o, 430°/30 C_a..............		100	60.1	.47	
		27. Fe-Cr-C, Cr-Steels				
3A	480°/120 C_a...	Cr, 12; C, 0.08 (*v. also* Figs. 3 and 4)	10	52.0	0.44	(16)
B	540°/120 C_a...		10	54.1	.47	
C	980°/90 Q_o { 595°/120 C_a...		10	42.9	.56	
D	705°/120 C_a...		10	30.7	.54	
E	980°/120 C_f..............		10	21.8	.49	
4	As received...............	Cr, 12; C, 0.25	12	37.8	.48	(22)
5A	900°/60 Q_w { 540°/60 C_a....	Cr, 12; C, 0.42	10	61.9	.51	(16)
B	650°/60 C_a....		10	43.9	.51	
6	As received...............	Cr, 13; C, 0.32	12	33.8	.44	(14)
7	As received, R_h...........	Cr, 13.2; C, 0.1‖	100	34.5	.44	(20)
8	As received...............	Cr, 13; C, 0.08	12	21.2	.45	(14)
9	To $PL \cong 42$..............	Cr, 13; C, 0.2	100	33.0	.48	(16)
11A	480°/60 C_a ...	Cr, 15; C, 0.85	10	73.1	.45	(16)
B	900°/60 Q_w { 565°/60 C_a ...		10	63.4	.54	
C	650°/60 C_a ...		10	51.0	.55	
D	As received, A............		10	35.1	.45	
12A	480°/60 C_a....	Cr, 15; C, 0.4	10	59.4	.51	(16)
B	900°/60 Q_w { 565°/60 C_a....		10	43.9	.51	
C	650°/60 C_a....		10	41.8	.52	
D	As received, A............		10	34.8	.45	

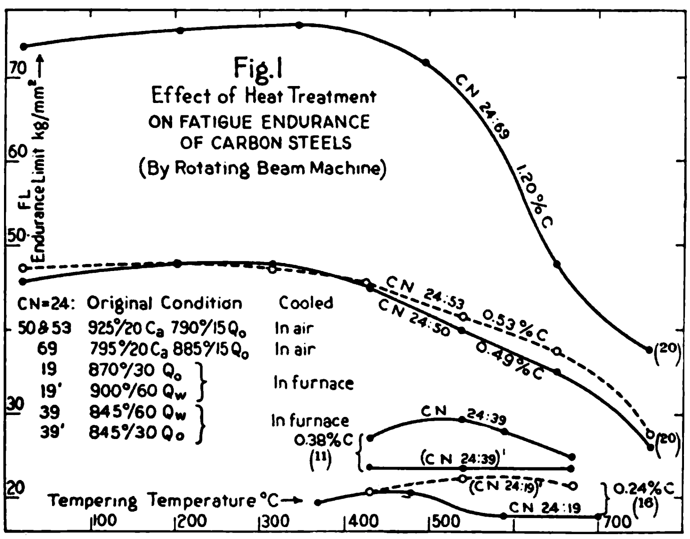

Fig. 1 Effect of Heat Treatment ON FATIGUE ENDURANCE OF CARBON STEELS (By Rotating Beam Machine)

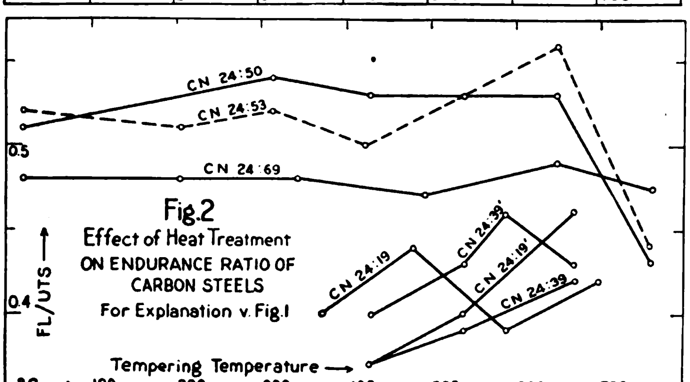

Fig. 2 Effect of Heat Treatment ON ENDURANCE RATIO OF CARBON STEELS For Explanation v. Fig. 1

Table 3.—Endurance Limits Under Reversed Bending Stresses (Rotating Beam Machines).*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_0}{UTS}$	Lit.
		27. Fe-Cr-C, Cr-Steels.—(*Continued*)				
13A	900°/60 Q_w, 480°/60 C_a....	Cr, 16; C, 0.6	10	80.5	0.57	(16)
B	As received, A............		10	38.3	.55	
		29. Fe-Cr-Mo-C, Cr-Mo-Steels				
3A	870°/60 C_f................	Cr, 0.76; Mo, 0.18; C, 0.39	10	27.1	0.45	(16)
B	870°/60 Q_w { 480°/60 C_f....		10	47.9	.56	
C	590°/60 C_f....		10	48.1	.50	
5A	870°/60 C_f................	Cr, 0.85; Mo, 0.20; C, 0.31	10	25.7	.44	(16)
B	870°/60 Q_w { 480°/60 C_f....		10	51.0	.44	
C	590°/60 C_f....		10	44.6	.45	
8	To $PL \cong 42$..............	Cr, 0.95; Mo, 0.1; C, 0.4	100	33.0	.51	(16)
12A	870°/60 C_f................	Cr, 1.0; Mo, 0.2; C, 0.50	10	34.8	.45	(16)
B	870°/60 Q_w { 480°/60 C_f....		10	61.9	.51	
C	590°/60 C_f...		10	53.1	.49	
13	To $PL \cong 77$..............	Cr, 1; Mo, 0.1; C, 0.4	100	47.5	.48	(16)
		30. Fe-Cr-V-C, Cr-V-Steels				
3	H, Tp....................	Cr, 0.95; V, 0.2 ; C, 0.44	10	51.7	0.52	(1)
4A	900°/60 C_f................	Cr, 1.0 ; V, 0.2; C, 0.55	10	31.3	.44	(16)
B	900°/60 Q_w { 480°/60 C_f....		10	66.4	.47	
C	590°/60 C_f....		10	64.7	.56	
5	Sv.......................	Cr, 1.0; V, 0.16; C, 0.45	10	32.0	.44	(16)
6	To $PL \cong 42$..............	Cr, 1.2; V, 0.2; C, 0.24	100	25.4	.45	(16)
7	To $PL \cong 77$..............	Cr, 1.5; V, 0.2 ; C, 0.53	100	47.0	.46	(16)
8	850° Q_o, 650° C_a..........	Cr, 1.5; V, 0.33; C, 0.46	12	43.3	.49	(14)
9	As received, R_h...........	Cr, 13.5; V, 0.3; C, 0.03	200	28.2	.49	(19)
		32. Fe-Ni-C, Ni-Steels				
2A	N 810°..................	Ni, 3.0; C, 0.4	10	33.9	0.43	(14)
B	850° Q_o, 620° Q_w..........		10	34.7	.44	
4	As taken from service¶......	Ni, 3.1; C, 0.4	10	31.3	.47	(16)

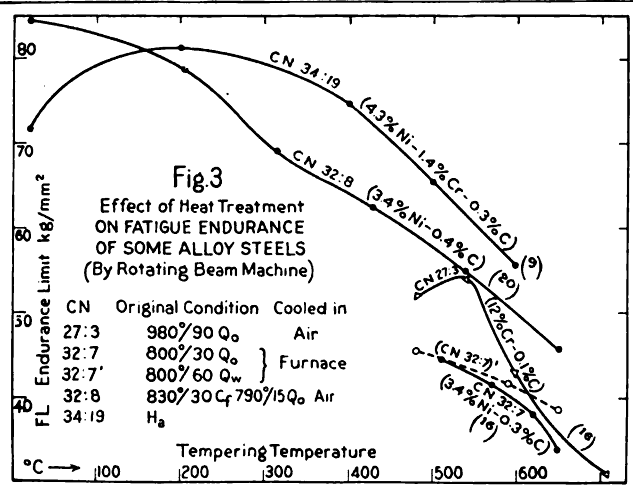

Fig. 3 Effect of Heat Treatment ON FATIGUE ENDURANCE OF SOME ALLOY STEELS (By Rotating Beam Machine)

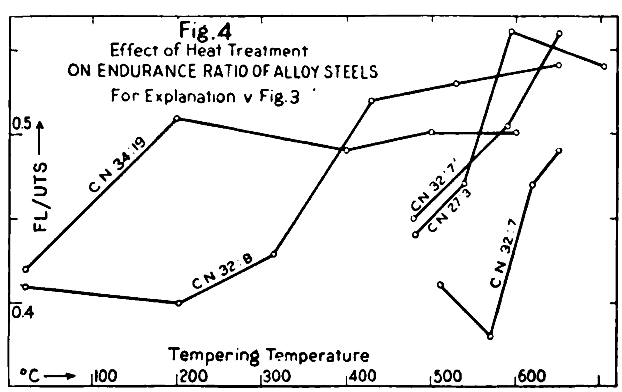

Fig. 4 Effect of Heat Treatment ON ENDURANCE RATIO OF ALLOY STEELS For Explanation v Fig. 3

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES).*—(*Continued*)

33. Fe-Ni-C, Ni-Steels.—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	FL_0/UTS	Lit.
7A	900°/120 Q_o, 800°/30 C_f	Ni, 3.4; C, 0.3	10	28.5	0.48	(16)
C	800°/60 C_f		10	34.8	.48	
D	800°/30 C_a		10	29.9	.47	
E	800°/30 Q_o { 650°/30 C_f	(*v. also* Figs. 3 and 4)	10	33.4	.49	
F	620°/30 C_f		10	38.0	.47	
G	800°/60 Q_o, 590°/60 C_f		10	33.7	.49	
H	800°/30 Q_o { 570°/30 C_f		10	41.8	.38	
J	510°/30 C_f		10	44.6	.41	
K	800°/60 Q_o 480°/30 C_f		10	38.3	.46	
L	800°/60 Q_w { 650°/60 C_f		10	38.7	.56	
M	590°/60 C_f		10	41.5	.51	
N	480°/60 C_f		10	45.3	.45	
8A	830°/30 C_f, 830°/15 Q_o { 590°/120 C_f	Ni, 3.4; C, 0.4	100	45.0	.52	(20)
B	650°/120 C_f		100	44.3	.53	
C	830°/30 C_f, 810°/15, C to 500°, Q_w, S_h, W_s 590°/60 C_f		100	45.0	.55	
D	785°/60 C_f		100	38.0	.53	
E	830°/30 C_f, 790°/15 Q_o	(*v. also* Figs. 3 and 4)	100	84.4	.41	
F	Same, Tp { 205°/30 C_a		100	78.8	.40	
G	315°/30 C_a		100	68.9	.43	
H	430°/30 C_a		100	62.6	.52	
J	540°/30 C_a		100	54.8	.53	
K	650°/30 C_a		100	45.7	.54	
10A	790°/60 C_f	Ni, 3.6; C, 0.4	10	35.9	.45	(16)
B	790°/30 Q_o, 620°/30 C_f		10	41.8	.48	
C	790°/60 Q_o, 480°/60 C_f		10	46.7	.56	
D	790°/60 Q_w { 590°/60 C_f		10	50.6	.54	
E	540°/60 C_f		10	52.4	.50	
F	480°/60 C_f		10	52.0	.48	
11	To $PL \cong 42$	Ni, 3.7; C, 0.3	100	32.4	.50	(16)
14	N 860°, 760° Q_w	Ni, 4.8; C, 0.14	10	41.8	.44	(14)
15	N 860°	Ni, 5.10; C, 0.13	6	37.7	.66	(28)
16	R, H 730°	Ni, 5.76; C, 0.11	12	41.5	.51	(1)

34. Fe-Ni-Cr-C, Ni-Cr-Steels

Key No.†	Treatment	Ni	Cr	C	$10^{-6}n$†	FL_0*	FL_0/UTS	Lit.
1	To $PL \cong 42$	0.47	1.10	0.43	100	27.6	0.42	(16)
4	Sv	1.41	0.81	.46	10	44.6	.45	(16)
5	To $PL \cong 77$	1.45	1.10	.41	100	38.6	.41	(16)
6A	845°/60 C_f	1.75	0.99	.49	10	35.1	.43	(16)
B	845°/60, Q_w Tp { 590°				10	50.6	.50	
C	480°				10	59.4	.51	
10	R 850°, H 770°	3.00	.48	.19	12	48.8	.47	(9)
11	R 840°, H 770°	3.15	.58	.20	12	46.5	.38	(9)
12A	To $PL \cong 42$	3.18	.96	.33	100	28.1	.39	(16)
B	To $PL \cong 77$				100	42.2	.45	
14A	A, 830° Q_o, 330° Q_o	3.33	.87	.24	100	47.8	.49	(20)
B	A, 830°/30 Q_o, 790° Q_o Tp { 650°/60 C_f				100	45.7	.57	
C	650°/60 Q_w				100	47.1	.59	
D	A 830°/30 C_a, 790°/30 C_f				100	34.4	.56	
15A	830°/30 C_f, 790°/15 Q_o { 425°/30 C_a	3.33	.18	.41	10	53.5	.46	(20)
B	650°/30 C_a				10	52.1	.59	
16	850° Q_o Tp 600°	3.45	.76	.32	12	44.2	.45	(14)
17	H, Tp	3.48	.78	.32	12	52.0	.50	(9)
19A	H_a (fully)	4.30	1.40	.30	12	71.6	.42	(9)
B	Same, Tp { 200°	(*v. also* Figs. 3 and 4) "Air-hardening steel"			12	81.2	.51	
C	400°				12	74.8	.49	
D	500°				12	65.3	.50	
E	600°				12	55.6	.50	
20	R 820°, H 760°	4.65	0.29	.16	12	47.2	.50	(22)
21A	R_h (2 passes); R_o	19.7	8.31	.33	10	38.7	.48	(20)
B	Same, W 940°/30 C_f (stainless steel, cyclops metal)				80	39.4	.50	

35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	FL_0/UTS	Lit.
1	As received, A	Ni, 12; Cr, 19; C, 0.8	10	46.0	0.53	(16)
2	As received, A	Ni, 16; Cr, 16; C, 0.4	10	45.0	.49	(16)
3	As received, A	Ni, 23; Cr, 5.4; C, 0.25	10	35.2	.52	(16)
4	As received, A	Ni, 25; Cr, 18; C, 0.4	10	38.0	.46	(16)
5	As received, A	Ni, 26; Cr, 17.3; C, 0.7	10	39.0	.52	(16)
6	As received, A	Ni, 28; Cr, 8.4; C, 0.45	10	41.1	.53	(16)

TABLE 3.—ENDURANCE LIMITS UNDER REVERSED BENDING STRESSES (ROTATING BEAM MACHINES).*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	FL_0/UTS	Lit.
	37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels					
9	Not stated	Ni, 4.8; Cr, 1; Mo, 0.9; C, 0.3	12	51.2	0.42	(14)
	38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels					
3	To Specification S2, British Air Ministry	Ni, 3.3; Cr, 0.6; V, 0.1; C, 0.3	12	53.5	0.56	(22)
	39. Fe-Ni-Mo-C, Ni-Mo-Steels					
1A	To $PL \cong 42$	Ni, 1.70; Mo, 0.12; C, 0.4	100	32.8	0.44	(16)
B	To $PL \cong 77$		100	40.1	.43	
	42. Fe-Si-Mn-C, Si-Mn-Steels					
1A	To $PL \cong 42$	Si, 2.0; Mn, 0.65; C, 0.55	100	34.5	0.44	(16)
B	To $PL \cong 77$	(Spring steels)	100	43.6	.39	
	43. Fe-V-C, V-Steels					
1A	870°/60 C_a, 840°/45 Q_w, 650°/60, C to 480° C_a	V, 0.16; C, 0.57	100	40.1	0.53	(19)
B	870°/60 C_a, 650°/30 C_a, 870°/120 Q_w, 700°/60 C_a		100	36.6	.51	
C	870°/60 C_a, 650°/60 C_a		50	43.0	.54	
	44. Mg, Commercial					
1	E	Mg, 99.96	150	5.5	0.24	(19)
2	R_h	Mg, 99.89	20	7.1	.30	(22)
	45. Mg-Al					
1	E	Al, 4.2	600	8.4	0.34	(19)
2	E	Al, 4.4	100	10.6	.39	(19)
3	R_h	Al, 6.0	20	11.3	.36	(22)
4	E	Al, 6.70	600	9.2	.31	(19)
5	E	Al, 6.80	80	10.6	.35	(19)
6A	F, longitudinal	Al, 8.7	60	10.5	.36	(19)
B	F, transverse		60	9.1	.42	
C	As cast		60	8.8	.45	
	46. Mg-Cu					
1	E	Cu, 9.65	600	7.7	0.28	(19)
	47. Mg-Zn					
1	As received, electron metal	Zn, 4.38	200	12.0	0.47	(19)
	48. Ni, Commercial					
1	R_h	Ni, 99.32	12	20.5	0.40	(13)
2A	As received, R_h	Ni, 99.07	400	16.9	.40	(16)
2B	760°/60 C_f		300	22.2	.41	
3	D_d 870° C_f	Ni, 99+	200	19.7	.41	(20)
4A	As received, R_o, A 288°	Ni, 98.95	100	28.1	.24	(16)
B	R_oW { 288°/60 C_f		60	28.1	.24	
C	288°/60 C_f		70	28.1	.25	
D	595°/60 C_f		70	34.4	.34	
E	760°/60 C_f		30	19.0	.37	
F	870°/60 C_f		50	17.9	.36	
5A	As received { D_c	Ni, 98.7	60	26.4	.37	(16)
B	D_c, 870°/60 C_f		60	20.4	.37	
	50. Ni-Cu					
1A	As received, R_o	Cu, 21.3 (Monel metals)	500	21.1	0.34	(16)
B	R_o, 870°/60 C_f		50	18.3	.33	
2A	As received, R_o	Cu, 23.6 (Monel metals)	100	23.9	.36	(16)
B	R_o, 870°/60 C_f		C§	20.7	.35	
3	R_h, A 760°	Cu, 28 (Monel metals)	70	26.4	.43	[illegible]
4	As received, R_h	Cu, 27.3 (Monel metals)	500	22.5	.36	[illegible]
5A	As received { D_c	Cu, 28.6 (Monel metals)	60	24.3	.37	[illegible]
B	D_c, 290°/60 C_f		60	25.3	.37	
C	D_c, 870°/60 C_f		60	19.7	[illegible]	
6	As received, R_h	Cu, 29.7 (Monel metals)	100	29.5	[illegible]	[illegible]
7A	R_h	Cu, 29.5 (Monel metals)	400	26.7	[illegible]	[illegible]
B	870°/60 Cf		C§	22.9	[illegible]	
8	R_h	Cu, 30	75	[illegible]	[illegible]	[illegible]
10A	As received, R_h	Cu, 44.2	50	18.7	[illegible]	[illegible]
B	Same, 815°/60 C_f		40	[illegible]	[illegible]	
	51. Ni-Cu-Mn					
2A	As received { R_h	Cu, 26.2; Mn, 4.3	60	27.4	0.43	(16)
B	R_h, 870°/60 C_f		C§	26.6	.43	

* Stresses computed by usual formulae of beam theory. † *See* footnotes to corresponding columns in Table 2. ‡ 22.5 mm diam. § C, calculated value. (Author assumes FL_0/UTS the same for the different treatments.) ‖ Stainless iron. ¶ Battleship propeller shaft.

TABLE 4.—ENDURANCE LIMITS UNDER REVERSED PLANE BENDING STRESSES (UPTON-LEWIS MACHINE)*

Key No.†	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$†	Endurance limit, kg/mm², FL_0 [Def. 17(b)]*	Endurance limit / Tensile strength	Lit.
	23. Fe, Commercially Pure					
2A	As received, A_b (ingot iron)	C, 0.02	2	16.2	0.54	(20)
	24. Fe-C, C-Steels					
37B	810°/15 C_{fo}	C, 0.37	2	21.0	0.42	(20)
40	870° Q_w, 420°/60 C_a	C, 0.40	2	48.0	.40	(8)
44A	875° Q_o, 400°/60 C_a	C, 0.44	2	62.5	.48	(8)
B	875° Q_o, 450°/60 C_a		2	60.0	.50	
50B	925°/20 C_a	C, 0.49	2	19.5	.31	(20)
C	Same, 775° Q_w, 650° C_f		2	27.5	.40	
52A	845°/15 C_a	C, 0.52	2	22.5	.33	(20)
B	Same, 790°/15 Q_w, 650° C_a		2	31.0	.40	
66B	870°/15 C_a, 790°/15 C_f	C, 0.93	2	20.0	.34	(20)
C	870°/15 C_a, 790°/15 Q_o, 650°/30 C_a		2	31.0	.38	
D	870°/15 C_a, 790°/15 Q_o, 455°/30 C_a		2	48.5	.37	
69A	795°/15 C_f, 860°/15 C_{fo}	C, 1.20	2	31.5	.38	(20)
	26. Fe-Ce-C, Ce-Steels					
1A	870° Q_w, 360°/60 C_a	Ce, 0.4–0.6; C, 0.38	2	56.0	0.44	(8)
B	870° Q_w, 420°/60 C_a		2	49.5	.45	
	27. Fe-Cr-C, Cr-Steels					
1A	900° Q_o, 425°/60 C_a	Cr, 0.94; C, 0.35	2	55.0	0.40	(8)
B	900° Q_o, 525°/60 C_a		2	56.0	.51	
C	900° Q_o, 625°/60 C_a		2	40.0	.45	
	28. Fe-Cr-Ce-C, Cr-Ce-Steels					
1A	900° Q_o, 425°/60 C_a	Cr, 0.98; Ce, 0.41–0.50; C, 0.41	2	59.0	0.39	(8)
B	900° Q_o, 525°/60 C_a		2	50.5	.48	
C	900° Q_o, 625°/60 C_a		2	41.5	.49	
	29. Fe-Cr-Mo-C, Cr-Mo-Steels					
1A	925° Q_o, 425°/60 C_a	Cr, 0.55; Mo, 0.39; C, 0.42	2	67.0	0.46	(8)
B	925° Q_o, 525°/60 C_a		2	64.5	.53	
C	925° Q_o, 630°/60 C_a		2	55.5	.61	
2A	925° Q_w, 425°/60 C_a	Cr, 0.73; Mo, 0.28; C, 0.15	2	43.0	.39	(8)
B	925° Q_w, 525°/60 C_a		2	48.5	.55	
C	925° Q_w, 625°/60 C_a		2	36.5	.54	
4A	850° Q_w, 425°/60 C_a	Cr, 0.79; Mo, 0.34; C, 0.22	2	56.2	.58	(8)
B	850° Q_w, 525°/60 C_a		2	52.5	.55	
C	850° Q_w, 625°/60 C_a		2	40.0	.49	
6A	820° Q_o, 425°/60 C_a	Cr, 0.88; Mo, 0.30; C, 0.40	2	69.0	.48	(8)
B	820° Q_o, 525°/60 C_a		2	61.1	.52	
C	820° Q_o, 625°/60 C_a		2	49.0	.52	
7A	900° Q_o, 525°/60 C_a	Cr, 0.89; Mo, 0.36; C, 0.41	2	60.0	.48	(8)
B	840° C_a		2	45.5	.50	
9A	815° Q_o, 425°/60 C_a	Cr, 0.95; Mo, 0.39; C, 0.52	2	70.5	.48	(8)
B	815° Q_o, 525°/60 C_a		2	64.5	.49	
C	815° Q_o, 625°/60 C_a		2	42.0	.45	
10A	900° Q_o, 425°/60 C_a	Cr, 0.95; Mo, 0.68; C, 0.40	2	68.0	.44	(8)
B	900° Q_o, 525°/60 C_a		2	60.0	.42	
C	900° Q_o, 625°/60 C_a		2	62.5	.51	
D	820° C_a		2	47.0	.45	
11A	925° Q_o, 425°/60 C_a	Cr, 0.95; Mo, 0.73; C, 0.25	2	60.5	.46	(8)
B	925° Q_o, 525°/60 C_a		2	57.0	.46	
C	925° Q_o, 600°/60 C_a		2	50.5	.48	
	30. Fe-Cr-V-C, Cr-V-Steels					
1A	900° Q_o, 425°/60 C_a	Cr, 0.93; V, 0.16; C, 0.41	2	62.0	0.42	(8)
B	900° Q_o, 525°/60 C_a		2	52.0	.40	
C	900° Q_o, 625°/60 C_a		2	52.0	.48	
D	900° C_a		2	46.0	.52	
2A	900° Q_o, 425°/60 C_a	Cr, 0.93; V, 0.20; C, 0.40	2	69.0	.51	(8)
B	900° Q_o, 525°/60 C_a		2	55.5	.48	
C	900° Q_o, 625°/60 C_a		2	43.5	.43	
	31. Fe-Mo-C, Mo-Steels					
1	875° Q_o, 450°/60 C_a	Mo, 0.34; C, 0.44	2	69.0	0.50	(8)
2A	870° Q_w, 360°/60 C_a	Mo, 0.37; C, 0.38	2	67.5	.46	(8)
B	870° Q_w, 420°/60 C_a		2	59.5	.45	
C	840° C_a		2	35.0	.48	
3A	870° Q_w, 420°/60 C_a	Mo, 0.67; C, 0.41	2	64.0	.46	(8)
B	870° Q_w, 500°/60 C_a		2	64.5	.52	
C	840° C_a		2	38.0	.45	

TABLE 4.—ENDURANCE LIMITS UNDER REVERSED PLANE BENDING STRESSES (UPTON-LEWIS MACHINE).*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_0}{UTS}$	Lit.
	31. Fe-Mo-C, Mo-Steels.—(*Continued*)					
4A	875° Q_o, 475°/60 C_a	Mo, 0.73; C, 0.4	2	67.5	0.50	(8)
B	875° Q_o, 550°/60 C_a		2	60.0	.47	
5A	900° Q_o, 425°/60 C_a	Mo, 1.05; C, 0.46	2	69.0	.45	(8)
B	900° Q_o, 500°/60 C_a		2	67.5	.48	
C	900° Q_o, 600°/60 C_a		2	67.5	.49	
D	900° C_a		2	52.0	.53	
6A	900° Q_o, 425°/60 C_a	Mo, 3.0; C, 0.36	2	73.0	.48	(8)
B	900° Q_o, 500°/60 C_a		2	76.0	.55	
C	900° Q_o, 575°/60 C_a		2	81.0	.65	
	32. Fe-Ni-C, Ni-Steels					
3A	860° Q_o, 415°/60 C_a	Ni, 3.0; C, 0.41	2	77.5	0.43	(8)
B	860° Q_o, 510°/60 C_a		2	63.5	.47	
C	860° Q_o, 595°/60 C_a		2	60.0	.50	
8A	830°/30 C_f, 590°/120 C_f	Ni, 3.4; C, 0.41	2	37.0	.43	(20)
B	830°/15 Q_o, 650°/120 C_f		2	32.5	.39	
D	785°/60 C_f		2	31.5	.44	
	33. Fe-Ni-Ce-C, Ni-Ce-Steels					
1A	860° Q_o, 595°/60 C_a	Ni, 2.86; Ce, 0.33–0.58; C, 0.43	2	53.5	0.45	(8)
B	860° Q_o, 455°/60 C_a		2	58.5	.42	
C	860° Q_o, 425°/60 C_a		2	67.5	.40	
	34. Fe-Ni-Cr-C, Ni-Cr-Steels					
2	825° Q_o, 525°/60 C_a	Ni, 1.23; Cr, 0.65; C, 0.47	2	58.5	0.52	(8)
7	865° Q_o, 475°/60 C_f	Ni, 2.49; Cr, 0.83; C, 0.37	2	60.0	.50	(8)
8A	810° Q_o, 525°/60 C_a	Ni, 2.56; Cr, 0.83; C, 0.36	2	48.0	.45	(8)
B	810° Q_o, 625°/60 C_a		2	46.0	.52	
14A	A, 830° Q_o, 330° Q_o	Ni, 3.33; Cr, 0.87; C, 0.24	2	36.5	.37	(20)
B	A, 830°/30 Q_o, 650°/60 C_f		2	32.5	.41	
C	790° Q_o, 650°/60 Q_w		2	35.0	.44	
	36. Fe-Ni-Cr-Ce-C, Ni-Cr-Ce-Steels					
1A	810° Q_o, 525°/60 C_a	For compositions s. Table 1	2	53.0	0.46	(8)
B	810° Q_o, 420°/60 C_a		2	68.0	.45	
2	825° Q_o, 525°/60 C_a		2	58.0	.55	(8)
3	805° Q_o, 500°/60 C_f		2	56.5	.50	(8)
4	810° Q_o, 525°/60 C_a		2	54.0	.50	(8)
	37. Fe-Ni-Cr-Mo-C, Ni-Cr-Mo-Steels					
1A	825° Q_o, 625°/60 C_a	For compositions s. Table 1	2	52.0	0.41	(8)
B	825° Q_o, 425°/60 C_a		2	70.5	.45	
2	825° Q_o, 525°/60 C_a		2	62.0	.52	(8)
3A	790° Q_o, 630°/60 C_a		2	49.5	.43	(8)
B	790° Q_o, 525°/60 C_a		2	61.0	.42	
C	790° Q_o, 430°/60 C_a		2	72.0	.43	
4	865° Q_o, 625°/60 C_f		2	48.5	.43	(8)
5	810° Q_o, 625°/60 C_a		2	56.0	.51	(8)
6A	810° Q_o, 650°/60 C_a		2	50.5	.46	(8)
B	810° Q_o, 625°/60 C_a		2	58.5	.49	
C	810° Q_o, 525°/60 C_a		2	70.5	.49	
D	810° Q_o, 425°/60 C_a		2	67.5	.44	
E	810° Q_o, 325°/60 C_a		2	70.5	.41	
F	810° Q_o, 150°/60 C_a		2	95.0	.43	
7	790° Q_o, 610°/60 C_a		2	47.0	.40	(8)
8	790° Q_o, 635°/60 C_a		2	50.5	.44	(8)
	38. Fe-Ni-Cr-V-C, Ni-Cr-V-Steels					
1	825° Q_o, 525°/60 C_a	For compositions s. Table 1	2	62.0	0.55	(8)
2A	810° Q_o, 625°/60 C_a		2	53.0	.49	(8)
B	805° Q_o, 560°/60 C_f		2	50.0	.44	
C	810° Q_o, 425°/60 C_a		2	70.5	.48	
	39. Fe-Ni-Mo-C, Ni-Mo-Steels					
2A	860° Q_o, 620°/60 C_a	Ni, 2.95; Mo, 0.70; C, 0.37	2	65.0	0.52	(8)
B	860° Q_o, 595°/60 C_a		2	65.0	.50	
	40. Fe-Ni-V-C, Ni-V-Steels					
1A	870° Q_o, 610°/60 C_a	Ni, 2.94; V, 0.12; C, 0.36	2	67.5	0.52	(8)
B	870° Q_o, 510°/60 C_a		2	74.0	.51	
C	870° Q_o, 400°/60 C_a		2	70.5	.38	
	41. Fe-Ni-Zr-C, Ni-Zr-Steels					
1	860° Q_o, 370°/60 C_a	Ni, 3.00; Zr, 0.24; C, 0.43	2	77.0	0.39	(8)
	43. Fe-V-C, V-Steels					
3A	900° C_a	V, 0.20; C, 0.50	2	46.0	0.52	(8)
B	840° Q_o, 555°/60 C_a		2	53.0	.51	
C	840° Q_o, 475°/60 C_a		2	56.5	.47	

* *See* footnote to Table 3. † *See* footnotes to Table 2.

TABLE 5.—ENDURANCE LIMITS UNDER REVERSED TORSIONAL STRESSES*

Key No.†	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$†	Endurance limit, kg/mm². FL_0 [Def. 17(b)]*	Endurance limit / Tensile strength	Lit.
		1. Al				
2	A, single crystal‡		15	1.17	0.22	(9.5)
		11. Cu, Electrolytic or Commercially Pure				
1	As received, R_c	Cu, 99.993	30	4.2	0.15	(16)
2	As received, R_h	Cu, 99.992	10	2.8	.13	(16)
		13. Cu-Al, Al-Bronzes				
4A	As received, R_h	Al, 5.6	30	7.9	0.16	(16)
6A	As received, R_h	Al, 9.1	20	7.0	.11	(16)
7A	As received, R_h	Al, 10.0	40	9.1	.16	(16)
12A	As received, R_h	Al, 10.4	60	12.0	.17	(16)
		17. Cu-Ni				
4A	As received, R_h	Ni, 44.7 (constantan)	30	10.2	0.21	(16)
B	As received, R_h, 790°/60 C_f		20	12.0	.24	
		18. Cu-Ni-Cr				
1A	As received, F	Ni, 34.2; Cr, 4.1	60	13.7	0.20	(16)
		20. Cu-Ni-Zn				
1A	As received, R_h	Ni, 20; Zn, 5	30	9.1	0.22	(16)
B	As received, R_h, 760°/60 C_f		30	9.1	.25	
		21. Cu-Sn, Bronzes				
3	As received, R_c	Sn, 4.66	70	8.4	0.21	(16)
		22. Cu-Zn, Brasses				
4	As received, R_c	Zn, 28.2	20	6.3	0.19	(16)
13A	Q_i, Tp 250°	Zn, 40.1 (Muntz metal)	6	3.9	.07	(16)
B	Q_i, Tp 344°		20	5.3	.09	
C	Q_i, Tp 425°		30	6.0	.12	
		23. Fe, Commercially Pure				
1A	A 1000°/30 C_f, Armco iron	C, 0.012	10	11.0	0.38	(9)
2A	As received, A_b, ingot iron	C, 0.02	10	8.8	.30	(20)
		24. Fe-C, C-Steels (%C)				
3	N 850°	0.13	10	16.5	0.34	(9)
19A	As received	.24	10	9.8	.23	(16)
20	As received, R	.25	10	11.0	.24	(9)
21	F	.25	10	11.6	.22	(16)
31	850°/15 C_a	.33	10	15.9	.27	(11)
37B	810°/15 C_{fo}	.37	10	11.2	.22	(20)
39A	845°/30 C_f	.38	10	12.7	.26	(20)
B	845°/30 C_a		10	12.3	.23	
C	930°/120 Q_o, 845°/30 C_f		10	11.2	.22	
D	845°/30 Q_o, 670°/30 C_f		10	15.1	.26	
E	845°/30 Q_o, 540°/30 C_f		10	11.6	.19	
F	845°/30 Q_o, 430°/30 C_f		10	14.4	.22	
42	As taken from service§	.41	10	10.2	.18	(16)
48	850°/60 Q_w, 480°/120 C_f	.46	10	20.0	.22	(16)
50B	925°/20 C_a	.49	10	14.1	.22	(20)
C	Same, 775° Q_w, 650° C_f		10	18.3	.27	
52A	845°/15 C_a	.52	10	15.5	.22	(20)
B	Same, 790°/15 Q_w, 650° C_a		10	22.2	.28	
60	N 800°	.65	10	15.2	.19	(9)
65A	790°/30 C_f	.81	10	13.4	.21	(16)
66B	870°/15 C_a, 790°/15 C_f	.93	10	11.5	.19	(20)
C	870°/15 C_a, 790°/15 Q_o, 650°/30 C_a		10	20.4	.25	
D	870°/15 C_a, 790°/15 Q_o, 455°/30 C_a		10	36.5	.28	
69A	795°/15 C_f, 860°/15 C_{fo}	1.20	10	17.2	.21	(20)
B	795°/15 C_f, 800° Q_o, 460°/15 C_a		10	33.7	.27	
		27. Fe-Cr-C, Cr-Steels (Stainless Steels)				
5A	900°/60 Q_w, 540°/60 C_a	Cr, 12; C, 0.42	10	30.2	0.39	(16)
B	900°/60 Q_w, 650°/60 C_a		10	26.0	.31	
7	As received, R_h‖	Cr, 13; C, 0.1	40	18.3	.23	(20)
11A	900°/60 Q_w, 480°/60 C_a	Cr, 15; C, 0.85	10	45.7	.28	(16)
B	900°/60 Q_w, 565°/60 C_a		10	41.5	.35	
C	900°/60 Q_w, 650°/60 C_a		10	26.0	.28	
D	As received, A		10	15.1	.19	

TABLE 5.—ENDURANCE LIMITS UNDER REVERSED TORSIONAL STRESSES.*—(*Continued*)

Key No.†	Treatment	Approximate composition	$10^{-6}n$†	FL_0*	$\frac{FL_0}{UTS}$	Lit.
12A	900°/60 Q_w, 480°/60 C_a	Cr, 15; C, 0.4	10	28.2	0.24	(16)
B	900°/60 Q_w, 565°/60 C_a		10	21.1	.24	
C	900°/60 Q_w, 650°/60 C_a		10	21.1	.26	
D	As received, A		10	16.9	.22	
13A	900°/60 Q_w, 480°/60 C_a	Cr, 16; C, 0.6	10	33.0	.24	(16)
B	As received, A		10	15.5	.21	
		30. Fe-Cr-V-C, Cr-V-Steels				
5	Sv	Cr, 1.0; V, 0.16; C, 0.45	10	15.1	0.21	(16)
		32. Fe-Ni-C, Ni-Steels				
4	As taken from service¶	Ni, 3.05; C, 0.4	10	16.5	0.25	(16)
7A	900°/120 Q_o, 800°/30 C_f	Ni, 3.35; C, 0.3	10	14.4	.24	(16)
B	840°/60 Q_w, 485°/60 C_f		10	37.2	.36	
C	800°/60 C_f		10	19.7	.27	
F	880°/30 Q_o, 620°/30 C_f		10	26.4	.33	
H	880°/30 Q_o, 570°/30 C_f		10	33.7	.30	
J	880°/30 Q_o, 510°/30 C_f		10	31.6	.29	
K	800°/60 Q_o, 480°/30 C_f		10	24.6	.30	
8A	830°/30 C_f, 830°/15 Q_o, 590°/120 C_f	Ni, 3.4; C, 0.4	10	26.0	.30	(20)
B	830°/30 C_f, 830°/15 Q_o, 650°/120 C_f		10	25.3	.31	
C	830°/30 C_f, 810°/15 Q_w, C to 500°, S_h 590°/60 C_f		10	23.2	.28	
D	785°/60 C_f		10	20.4	.29	
10A	790°/60 C_f	Ni, 3.6; C, 0.42	10	15.8	.20	(16)
C	790°/60 Q_o, 480°/60 C_f		10	26.7	.32	
D	790°/60 Q_w, 590°/60 C_f		10	32.7	.35	
F	790°/60 Q_w, 480°/60 C_f		10	33.0	.31	
12	840°/60 Q_w, 480°/120 C_f	Ni, 3.7; C, 0.3	10	25.3	.24	(16)
		34. Fe-Ni-Cr-C, Ni-Cr-Steels				
3	840°/60 Q_w, 480°/120 C_f	Ni, 1.36; Cr, 0.65; C, 0.37	10	32.3	0.29	(16)
14A	A 830° Q_o, 330° Q_o	Ni, 3.3; Cr, 0.87; C, 0.24	10	26.7	.27	(20)
B	A 830°/30 Q_o, 790° Q_o, 650°/60 C_f		10	22.1	.28	
C	A 830°/30 Q_o, 790° Q_o, 650°/60 Q_w		10	23.9	.30	
D	A, 830°/30 C_a, 790°/30 C_f		10	17.6	.29	
21A	R_h (2 passes), R_c (cyclops metal)	Ni, 19.7; Cr, 8.3; C, 0.33	10	26.1	.23	(20)
		35. Fe-Ni-Cr-Cu-C, Ni-Cr-Cu-Steels (Stainless Steels)				
3	As received, A	Ni, 23; Cr, 5.4; C, 0.24	10	14.8	0.22	(16)
6	As received, A	Ni, 28; Cr, 8.4; C, 0.45	10	15.5	.20	(16)
		43. Fe-V-C, V-Steels				
2	795°/60 Q_w, 480°/120 C_f	V, 0.16; C, 0.5	10	30.2	0.30	(16)
		48. Ni, Commercially Pure				
2A	As received, R_h	Ni, 99.07	70	14.1	0.33	(16)
4B	R_c, 288°/60 C_f	Ni, 98.95	20	13.0	.11	(16)
F	R_c, 870°/60 C_f		20	12.0	.24	
		50. Ni-Cu				
4	As received	Cu, 27.3	10	14.0	0.22	(20)
7A	R_h	Cu, 29.5	20	13.4	.21	(16)

* Stresses calculated by usual formulae of theory of elasticity.

† *See* footnotes to Table 2.

‡ The mechanical properties depend to some extent on the relative positions of the specimen and crystallographic axis.

§ Submarine crank-shaft.

‖ Stainless iron.

¶ Battleship propeller shaft.

TABLE 6.—ENDURANCE LIMITS UNDER CYCLES OF DIRECT STRESS WITH VARIOUS MEAN STRESSES

Key No.*	Treatment	Approximate composition	10^{-6} × number of reversals*	M, mean unit stress, kg/mm²	R/2, endurance half range [Def. 17(e)]	UTS, ultimate tensile strength	R/UTS	Lit.
		22. Cu-Zn, Brasses						
14A	As received, R.......	Cu, 58.5; Zn, 40.1	2 H	− 9.5	22.9	45.3	1.01	(12)
	Naval brass, αβ		2 H	− 5.1	21.6	45.3	0.955	
			2 H	0.0	18.9	45.3	.825	
			2 H	+ 6.3	16.5	45.3	.73	
			2 H	9.8	15.1	45.3	.665	
			2 H	12.2	13.8	45.3	.61	
		24. Fe-C, C-Steels						
4	R_h................	C, 0.13	8 H	−19.2	15.3	39.7	0.77	(12)
			8 H	−14.7	16.9	39.7	.85	
			8 H	− 8.2	18.5	39.7	.93	
			8 H	0.0	20.5	39.7	1.03	
			8 H	+ 7.8	19.3	39.7	0.97	
			8 H	15.5	16.9	39.7	.85	
			8 H	20.1	13.8	39.7	.695	
18A	As received..........	C, 0.24	1	0.0	22.7	59.2	.765	(25)
			1	15.1	15.1	59.2	.51	
B	A..................	C, 0.24	1	0.0	20.7	57.6	.72	(25)
			1	14.6	14.6	57.6	.505	
23	As received, R.......	C, 0.27	1	0.0	21.2	51.5	.825	(25)
			1	16.2	16.2	51.5	.63	
25	As received, R.......	C, 0.29	1	0.0	21.7	54.7	.79	(25)
			1	16.7	16.7	54.7	.61	
32	As received..........	C, 0.34	1	0.0	22.8	58.5	.78	(25)
			1	17.1	17.1	58.5	.585	
38	As received, R.......	C, 0.38	1	0.0	23.3	62.0	.75	(25)
			1	17.6	17.6	62.0	.57	
51	As received..........	C, 0.51	1	0.0	20.3	70.4	.585	(25)
			1	15.2	15.2	70.4	.43	
54	As received..........	C, 0.57	1	0.0	26.8	73.6	.73	(25)
			1	20.2	20.2	73.6	.55	
57	As received..........	C, 0.62	1	0.0	22.4	72.6	.62	(25)
			1	17.6	17.6	72.6	.485	
58	As received..........	C, 0.63	1	0.0	28.0	81.0	.69	(25)
			1	21.4	21.4	81.0	.53	
62	As received..........	C, 0.72	1	0.0	21.2	89.0	.475	(25)
			1	18.3	18.3	89.0	.41	
64	As received..........	C, 0.79	1	0.0	23.6	63.1	.75	(25)
			1	16.7	16.7	63.1	.53	
		32. Fe-Ni-C, Ni-Steels						
5	As received, R.......	Ni, 3.1; C, 0.12	1	0.0	22.8	46.0	0.955	(25)
			1	18.3	18.3	46.0	.795	
6	As received, R.......	Ni, 3.25; C, 0.38	1	0.0	30.9	50.4	1.23	(25)
			1	14.2	27.6	50.4	1.10	
			1	22.1	22.1	50.4	0.875	
			1	27.3	17.9	50.4	.71	
8A	830°/30 C_f, 830°/15 Q_o 590°/120 C_f.........	Ni, 3.4; C, 0.41	10	0.0	30.9	87.0	.71	(20)
			10	3.4	30.4	87.0	.70	
8B	830°/30 C_f, 830°/15 Q_o 650°/120 C_f.........		10	0.0	26.0	78.6	.66	(20)
			10	3.4	31.0	78.6	.79	
			10	11.0	25.6	78.6	.65	
8D	785°/60 C_f..........		10	0.0	25.7	71.5	.72	(20)
			10	9.3	21.6	71.5	.605	
9A	As received, R.......	Ni, 3.56; C, 0.14	1	0.0	27.0	50.0	1.08	(25)
			1	17.3	17.3	50.0	0.69	
13	As received, R.......	Ni, 4.7; C, 0.50	1	0.0	29.7	63.4	.94	(25)
			1	21.6	21.6	63.4	.825	

TABLE 6.—ENDURANCE LIMITS UNDER CYCLES OF DIRECT STRESS WITH VARIOUS MEAN STRESSES.—(*Continued*)

Key No.*	Treatment	Approximate composition	10^{-6} × number of reversals*	M, mean unit stress, kg/mm²	R/2, endurance half range [Def. 17(e)]	UTS, ultimate tensile strength	R/UTS	Lit.
		34. Fe-Ni-Cr-C, Ni-Cr-Steels						
18	Treatment not stated	Ni, 3.6; Cr, 0.6; C, 0.30	8 H	−15.8	42.2	80.9	1.04	(15)
			8 H	0.0	36.2	80.9	0.895	
			8 H	+23.8	27.6	80.9	.685	
			8 H	28.3	26.8	80.9	.665	
			8 H	31.5	20.0	80.9	.495	
			8 H	39.4	14.6	80.9	.36	
			8 H	47.3	15.7	80.9	.39	
			8 H	53.9	11.3	80.9	.28	
			8 H	66.3	6.1	80.9	.15	

* *See* footnotes to Table 2.

TABLE 7.—ENDURANCE LIMITS UNDER CYCLES OF TORSIONAL STRESS WITH VARIOUS MEAN STRESSES

Key No.*	Treatment	Approximate composition	Millions of reversals, $10^{-6}n$*	M, mean unit stress, kg/mm²	R/2, endurance half range, kg/mm² [Def. 17(e)]	UTS, ultimate tensile strength, kg/mm²	R/UTS	Lit.
		24. Fe-C, C-Steels						
48	805°/60 Q_w, 480°/120 C_f...	C, 0.46	10	0.0	20.0	92.7	0.43	(16)
			10	14.1	21.1	92.7	.455	
			10	20.4	20.4	92.7	.44	
50B	925°/20 C_a..............	C, 0.49	10	0.0	14.0	64.3	.435	(20)
			10	3.4	13.5	64.3	.42	
			10	13.0	13.0	64.3	.405	
50C	925°/20 C_a, 775° Q_w, 650° C_f (sorbitic).		10	0.0	18.3	68.1	.54	(20)
			10	17.6	17.6	68.1	.52	
69A	795°/15 C_f, 860°/15 C_{fo}....	C, 1.20	10	0.0	17.2	82.2	.42	(20)
			10	17.2	17.2	82.2	.42	
69B	795°/15 C_f, 800° Q_o, 460°/15 C_a		10	0.0	33.7	126.5	.53	(20)
			20	31.3	31.3	126.5	.50	
		32. Fe-Ni-C, Ni-Steels						
7B	840°/60 Q_w, 485°/60 C_f....	Ni, 3.35; C, 0.31	10	0.0	37.3	102.5	0.73	(16)
			10	17.9	33.4	102.5	.65	
			10	33.4	33.4	102.5	.65	
			10	44.6	23.6	102.5	.46	
8A	830°/30 C_f, 830°/15 Q_o, 590°/120 C_f	Ni, 3.4; C, 0.4	10	0.0	26.0	86.9	.60	(20)
			10	24.6	24.7	86.9	.57	
8B	830°/30 C_f, 830°/15 Q_o, 650°/120 C_f		10	0.0	25.3	78.8	.645	
			10	5.5	21.9	78.8	.555	
8D	785°/60 C_f..............		10	0.0	20.4	71.4	.57	
			10	4.9	19.7	71.4	.55	
			10	20.0	20.0	71.4	.56	
12	840°/60 Q_w, 480°/120 C_f...	Ni, 3.74; C, 0.28	10	0.0	25.3	103.5	.49	(16)
			10	23.9	23.9	103.5	.46	
		34. Fe-Ni-Cr-C, Ni-Cr-Steels						
3	840°/60 Q_w, 480°/120 C_f...	Ni, 1.4; Cr, 0.65; C, 0.37	10	0.0	32.3	112.6	0.575	(16)
			10	30.6	30.6	112.6	.545	
14D	As received, A, 830°/30 C_a, 790°/30 C_f	Ni, 3.3; Cr, 0.87; C, 0.24	10	0.0	17.6	61.4	.58	(20)
			10	3.9	15.8	61.4	.52	
			10	16.2	16.2	61.4	.53	
		43. Fe-V-C, V-Steel						
2	795°/60 Q_w, 480°/120 C_f...	V, 0.16; C, 0.50	10	0.0	30.2	100.9	0.60	(16)
			10	28.5	28.5	100.9	.565	
			10	37.2	27.4	100.9	.545	

* *See* footnotes to Table 2.

Table 8.—Endurance Limits at Various Temperatures, Reversed Direct Stresses

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n$*	Endurance limit, kg/mm² FL_0 [Def. 17 (b)]	$(FL_0)_t/(FL_0)_{20}$	Lit.
	8. Al-Si						
6A	G_mM.............	Si, 12.7	15	10 H	6.0	1.00	(22)
			180	10 H	4.4	0.735	
	24. Fe-C, Carbon Steels						
60	N 800°............	C, 0.65	20	10 H	30.7	1.00	(9)
			305	10 H	23.5	0.765	
	25. Fe-C, Cast Irons						
1	As cast............	Graphite, 1.70; combined C, 0.56, "granfin"	20	6 H	15.0	1.00	(12)
			350	6 H	13.4	0.895	
			500	6 H	14.2	.945	
	32. Fe-Ni-C, Ni-Steels						
1	As received.........	Ni, 2.9; C, 0.4	20	10 H	31.7	1.00	(27)
			370	10 H	25.9	0.82	
	49. Ni-Cr						
1	As received, R_h.....	Ni, 80; Cr, 19	18	10 H	23.6	1.00	(22)
			200	10 H	24.8	1.05	
			300	10 H	27.9	1.18	
			400	10 H	27.9	1.18	
			600	10 H	24.8	1.05	
			700	10 H	24.0	1.01	
	51. Ni-Cu-Mn						
1	As received, R......	Ni, 69; Cu, 28; Mn, 2.4	15	10 H	25.1	1.00	(22)
			100	10 H	21.0	0.84	
			200	10 H	20.0	.80	
			300	10 H	20.0	.80	
			500	10 H	18.4	.73	
			600	10 H	14.1	.56	

* *See* footnotes to Table 2.

Table 9.—Endurance Limits at Various Temperatures. Reversed Bending Stresses (Rotating Beam Machines)

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n$*	Endurance limit kg/mm² FL_0 [Def. 17(b)]†	$(FL_0)_t/(FL_0)_{20}$	Lit
	3. Al-Cu-Mg						
5	R_h, 480° Q_wV	Cu, 4.0; Mg, 0.5	20	2	16.6	1.00	(13)
			150	2	11.3	0.68	
8	R_h, 480° Q_w V............	Cu, 5.0; Mg, 0.75	20	2	16.6	1.00	(13)
			150	3	12.5	0.75	
9	R_h, 480° Q_w V............	Cu, 6.0; Mg, 0.75	20	3	16.1	1.00	(13)
			150	3	7.9	0.49	
	4. Al-Cu-Ni-Mg						
1	R_h ("magnalite")..........	Cu, 2.0; Ni, 1.5; Mg, 1.0	20	4	14.2	1.00	(13)
			150	4	11.0	0.78	
4	480° Q_h V..............	"Y" alloys, Cu, 4; Ni, 2.0; Mg, 1.5	20	3	14.2	1.00	(13)
			150	3	10.3	0.73	
5	480° Q_h V................		20	3	16.3	1.00	(13)
			150	3	12.9	0.79	
6	520° Q_h V................		20	10	16.1	1.00	(13)
			150	3	13.2	0.82	
	6. Al-Mg						
1	R_h ("aeromin")...........	Mg, 6.2	20	3	10.3	1.00	(13)
			150	3	8.6	0.84	

Table 9.—Endurance Limits at Various Temperatures. Reversed Bending Stresses (Rotating Beam Machines).—(*Continued*)

Key No.*	Treatment	Approximate composition	Temp., °C	Millions of reversals, $10^{-6}n$*	Endurance limit kg/mm² FL_0 [Def. 17(b)]†	$(FL_0)_t/(FL_0)_{20}$	Lit.
	10. Al-Zn-Cu						
5	R_h, 350° Q V, "E" alloy....	Zn, 20; Cu, 2.5	20	2	15.3	1.00	(13)
			150	2	8.0	0.52	
6	R_h "A" alloy	Zn, 20.3; Cu, 2.9	20	2	13.7	1.00	(13)
			150	2	7.1	0.52	
	24. Fe-C, C-Steels						
50 B	925°/20 C_a...............	C, 0.49	21	18	25.3	1.00	(20)
			290	20	27.4	1.08	
			380	10	29.5	1.17	
			425	10	31.0	1.22	
			470	10	29.6	1.77	
			540	12	23.9	0.94	
			620	15	16.9	.67	
68	790°/30 C_f, 790°/30 Q_o ("spring steel")	C, 1.02	21	10	73.8	1.00	(20)
			165	10	68.4	0.93	
			305	10	60.5	.82	
			480	10	52.8	.72	
			565	12	38.0	.52	
	34. Fe-Ni-Cr-C, Ni-Cr-Steels						
15A	830°/30 C_f, 700°/15 Q_o, 425°/30 C_a	Ni, 3.3; Cr, 0.18; C, 0.41	20	10	53.5	1.00	(20)
			240	10	57.7	1.08	
			345	10	52.9	0.99	
			470	10	47.9	.90	
			540	10	40.9	.76	
15B	830°/30 C_f, 790°/15 Q_o, 650°/30 C_a		20	10	52.1	1.00	(20)
			240	10	52.7	1.01	
			345	10	47.1	0.90	
			470	10	43.6	.84	
			540	10	38.7	.74	
21B	R_h (2 passes), R_c, 940°/30 C_f ("cyclops metal")	Ni, 19.7; Cr, 8.3; C, 0.33	20	80	39.4	1.00	(20)
			260	13	36.6	0.93	
			470	20	32.4	.82	
			565	10	26.1	.66	

* *See* footnotes to Table 2.
† *See* footnote to Table 3.

LITERATURE

(For a key to the periodicals see end of volume)

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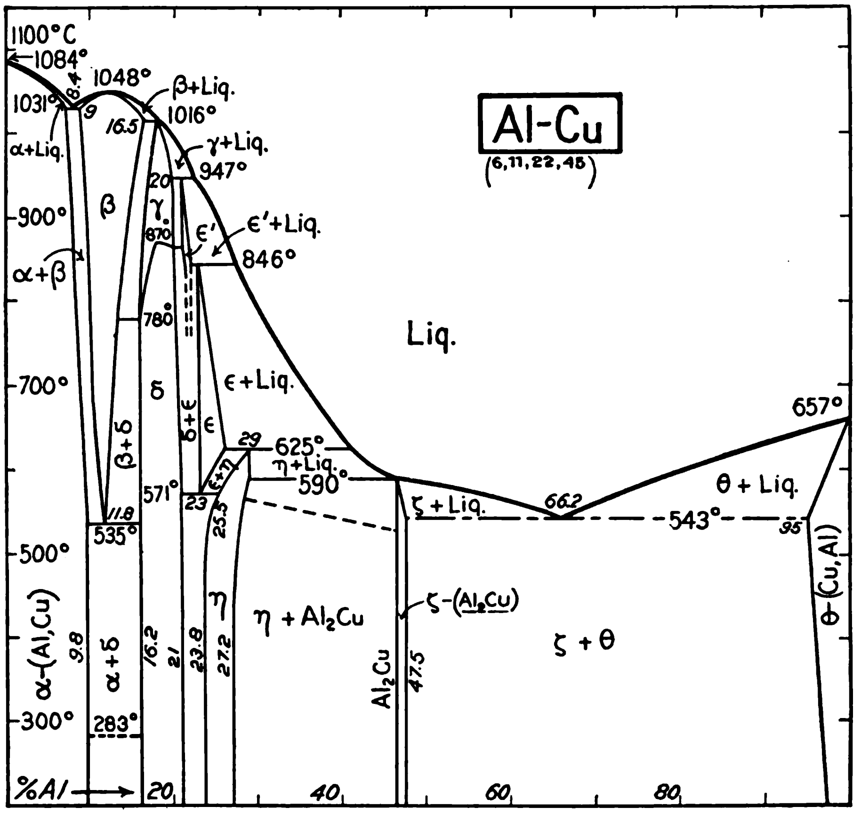
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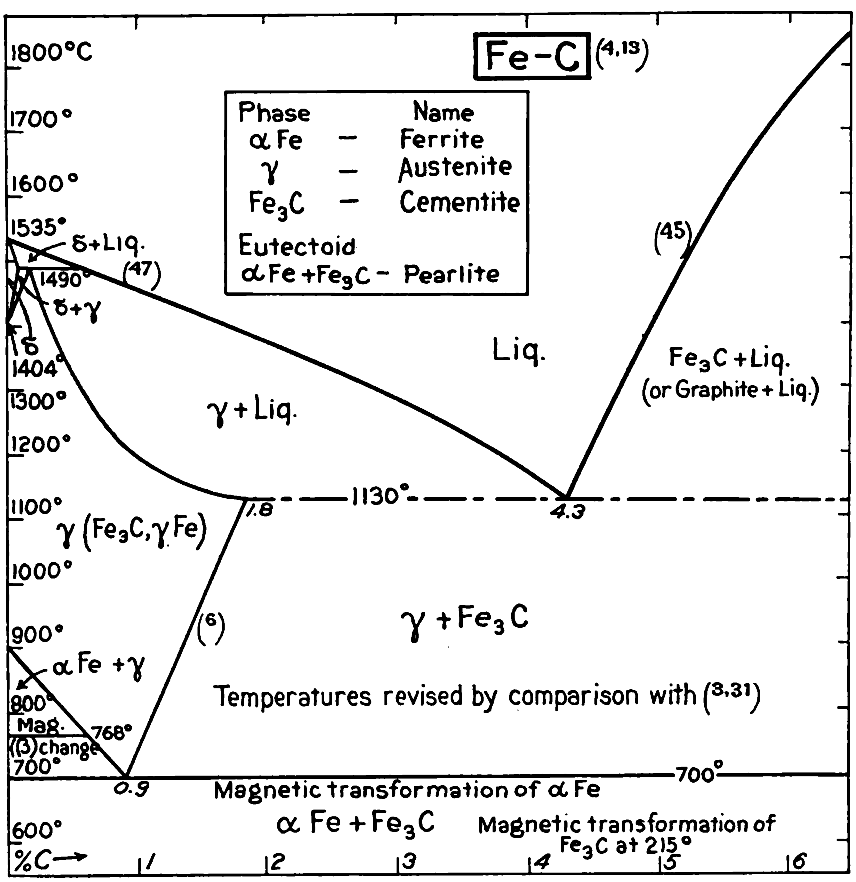
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768°
700°
600°
Phase — Name
α Fe — Ferrite
γ — Austenite
Fe_3C — Cementite
Eutectoid
α Fe + Fe_3C — Pearlite
δ+Liq.
δ+γ
δ
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(6)
Liq.
γ + Liq.
Fe_3C + Liq.
(or Graphite + Liq.)
1130°
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γ (Fe_3C, γ Fe)
γ + Fe_3C
α Fe + γ
Mag.
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0.9
Temperatures revised by comparison with (3,31)
Magnetic transformation of α Fe
α Fe + Fe_3C
Magnetic transformation of Fe_3C at 215°
%C
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SPECIAL PROPERTY-TABLE

The following tables are arranged to facilitate the selection of a metal or alloy having an extreme (high or low) value of a given mechanical property at room temperature. The bold-face numbers represent a scale of values of the property in question. The numbers in the interval between any two scale values are page numbers by means of which the reader may locate an alloy having a value (of the property in question) which lies within this interval.

ULTIMATE TENSILE STRENGTH, *UTS*, kg/mm² (DEF. 4)

Ferrous: **241**: 479, 513. **230**: 513, 530, 531. **220**: 478, 479, 509, 510, 513, 531, 532. **200**: 478, 479, 502, 503, 505, 509, 510, 512, 532. **180**: 479, 507, 511, 512, 513, 530, 531. **175**: . . . **20**: 488, 497, 498, 508, 526, 527. **10**: 488, 490, 497, 498, 508, 523, 527. **3.**
Non-ferrous: **420**: 592. **160**: 585, 592. **112**: 560, 573, 575, 576, 578, 579, 581, 582. **80**: 481, 560, 575–579, 581, 582, 583, 585, 592. **70**: 534, 538, 555, 556, 575–585, 592. **60**: 538, 546, 554, 555, 556, 560, 563, 574–585, 592. **50**: . . . **5**: 533, 535, 545, 546, 547, 549, 551, 553, 556, 557, 567, 570, 584, 592, 593. **1**: 586, 593. **0.**

YIELD POINT IN TENSION, *YP*, kg/mm² (DEF. 3)

Ferrous: **203**: 479, 513, 531. **190**: 478, 479, 510, 513. **180**: 478, 479, 511, 530, 531. **170**: 478, 479, 503, 507, 511, 531. **160**: 478, 479, 481, 510, 513. **151**: . . . **20**: 478, 480, 482, 488, 489, 490, 491, 493, 508, 514, 523. **10**: 482, 523. **3.6.**
Non-ferrous: **88**: 581, 582. **70**: 575, 579, 581–583. **60**: 481, 534, 538, 555, 556, 560, 575, 577–582. **40**: . . . **3.9**: 533, 534, 536, 537, 543, 552. **1.8.**

REDUCTION IN AREA, *RA*, % (DEF. 8)

Ferrous: **100**: 488, 490, 498. **80**: 478, 481, 488, 498, 523. **75**: . . . **2.2**: 491, 492, 493, 510, 513, 521, 529, 530, 531, 532. **1.0**: 479, 510, 513, 521, 524, 531. **0.0**: 490, 491, 492, 493, 497, 508, 510, 513, 520, 524, 529, 530, 532.
Non-ferrous: **100**: 592, 593. **95**: 533, 548, 549, 553, 574. **80**: 533, 536, 548, 549, 552, 553, 555, 560, 574, 581, 583. **77**: . . . **2.0**: 533, 545, 556, 557, 560, 562, 575, 579. **0.4**: 575, 579, 586, 593. **0.0.**

PER CENT ELONGATION, *El* (DEF. 7)

Ferrous: **76**: 488, 498, 512. **60**: 478, 482, 488, 490, 498, 512. **50**: . . . **1.0**: 491, 492, 493, 501, 503, 510, 513, 520, 521, 523, 524, 525, 530, 531, 532. **0.5**: 478, 490, 491, 492, 493, 508, 513, 521, 522, 523, 524, 525, 529, 530, 532. **0.0.**
Non-ferrous: **160**: 547, 576. **95**: 533, 535, 548, 551, 555, 557, 573–576, 581–583. **70**: . . . **1.0**: 480, 533, 534, 536, 537, 544, 545, 546, 551, 559–561, 565, 567, 568, 570, 575–577, 579, 581, 586. **0.0.**

BRINELL HARDNESS NUMBER, *BHN* (DEF. 12)

Ferrous: **817**: 495, 510, 514, 531. **600**: 495, 506, 510, 513, 514, 521, 523, 530, 531. **570**: 495, 503, 510, 513, 514, 523, 530, 531. **550**: 513, 514, 531. **520**: 506, 510, 513, 514, 532. **509**: . . . **99**: 478, 494, 525, 526. **90**: 478, 514, 525, 529. **80**: 478, 494, 529. **51.**
Non-ferrous: **540**: 576, 588. **390**: 561, 576, 588. **300**: 480, 567, 576, 577, 579, 581, 582, 586–588, 592, 593. **220**: 480, 556, 576, 577, 581–583, 586, 588. **190**: 480, 546, 556, 576, 577, 581–584, 586. **175**: 480, 539, 546, 556, 577, 580–582, 584, 585, 588. **160**: 480, 539, 554, 556, 577, 579–587. **154**: . . . **10**: 556, 557, 561, 576. **3.0.**

LITERATURE REFERENCES

LITERATURE REFERENCES

In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key Number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus *64V*, **31**: 253; 22, indicates Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key Numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in Roman numerals. Thus, *B10*, **IV**: 191; 18 indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The Key Number *O* is used to indicate "private communication from."

RÉFÉRENCES BIBLIOGRAPHIQUES

Le nom du journal ou de la publication de toutes les références bibliographiques citées dans les Tables Critiques Internationales est indiqué au moyen d'un nombre-clé correspondant à la liste donnée ci-dessous. Les nombres qui suivent ce nombre-clé dans un renvoi bibliographique indiquent dans l'ordre suivant: (1) le volume, (2) la page, et (3) les deux derniers chiffres de l'année. Ainsi *64V*, **31**: 253; 22, indique Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, vol. 31, page 253, 1922. Les numeros des séries ne sont pas donnés. Les nombres-clés se rapportant à des livres et à des publications non périodiques sont précédés de la lettre *B* et le numéro du volume est donné en chiffres romains. Ainsi, *B10*, **IV**: 191; 18 indique Doelter, Handbuch der Mineralchemie, page 191 du volume 4 de l'édition de 1918. Le nombre-clé *O* est employé pour indiquer "communication privée de."

DAS LITERATURVERZEICHNIS

In allen Literaturstellen, die in I. C. T. verzeichnet sind, ist der Name der Zeitschrift oder der Publikation mit Hilfe einer *Schlüsselnummer*, entsprechend der unten folgenden Liste, angegeben. Die Zahlen, welche diesen Schlüsselnummern bei einem Literaturzitat folgen, bedeuten der Reihe nach: (1) der Band, (2) die Seite und (3), die letzten zwei Zahlen des Jahrganges. So bedeutet z. B. *64V*, **31**: 253; 22, Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, Band 31, Seite 253, 1922. Serien-Nummern werden nicht angegeben. Der Schlüsselzahl wird ein *B* vorausgesetzt, wenn sie Bücher, oder eine andre nicht periodische Veröffentlichung bezeichnet. Die Bandnummer wird durch römische Ziffern angegeben. Es bedeutet z. B. also *B10*, **IV**: 191; 18, Doelter, Handbuch der Mineralchemie, Seite 191, des 4 Bandes, der Auflage des Jahres 1918. Die Schlüsselzahl *O* wird gebraucht, um anzuzeigen, dass es eine "private Mitteilung" ist.

INDICAZIONI BIBLIOGRAFICHE

In tutte le indicazioni bibliografiche che si incontrano nelle "Tabelle Critiche Internazionali" il nome del giornale o della pubblicazione è espresso con un *numero chiave* riportato nell'elenco dato più oltre. I numeri che, nella citazione, vengono dopo il numero chiave sono disposti con l'ordine seguente: (1) il volume, (2) la pagina, e (3) le ultime due cifre del millesimo. Cosi *64V*, **31**: 253; 22, indica la Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, pagina 253, 1922. I numeri di serie non vengono dati. Quando un numero chiave è preceduto dalla lettera *B* si riferisce a libri o ad altre pubblicazioni non periodiche, e il numero del volume viene allora scritto in cifre romane. Cosi *B10*, **IV**: 191; 18 indica Doelter, Handbuch der Mineralchemie, pagina 191 del IV° volume dell'edizione 1918. Il numero chiave *O* indica "Comunicazione privata da . . . "

KEY TO THE PERIODICALS

Data regarding the libraries which receive many of these periodicals may be found through the following sources:

United States and Canada: "Periodicals Abstracted by Chemical Abstracts, 1926" (Chemical Abstracts, Ohio State Univ., Columbus, Ohio); "Union List of Serials in the Libraries of the United States and Canada, 1925–1927" (H. W. Wilson & Co., New York City); "A Catalogue of Scientific Periodicals in Canadian Libraries, 1924" (McGill Univ., Montreal, Canada).

Great Britain: "A World List of Scientific Periodicals Published in the Years 1900–1921" (Oxford Univ. Press, London, 1925–).

Holland: "Chemisch Jaarboekje tevens Jaarboekje der Nederlandsche Chemische Vereeniging, Vol. 3." (Amsterdam, D. B. Centen, 1920.)

1. Journal of the American Chemical Society.
2. Physical Review.
3. London, Edinburgh and Dublin Philosophical Magazine and Journal of Science.
4. Journal of the Chemical Society, London. (Memoirs of the Chemical Society; *continued as* Quarterly Journal; *later* Journal.)
5. Proceedings of the Royal Society (London). A. Mathematical and Physical Sciences.

5B. Proceedings of the Royal Society (London). B. Biological Sciences.

6. Annales de chimie et de physique. *See also* Nos. 14 and 16.
7. Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre.
8. Annalen der Physik. [Journal der Physik, 1790–1794. Neues Journal der Physik, 1795–1796. Annalen der Physik, 1799–1819; Annalen der Physik und der physikalische Chemie, 1819–1824 (Gilbert). Annalen der Physik und Chemie, 1824–1899 (Poggendorff, Wiedemann). Annalen der Physik, 1900– (Drude, Wien and Planck).]
9. Zeitschrift für Elektrochemie und angewandte physikalische Chemie.
10. Tables annuelles internationales de constantes et données numériques.
11. American Chemical Journal. (*Combined with* No. 1 *in 1914.*)
12. American Journal of Science. (American Journal of Science and Arts, 1820–79; *known also as* Silliman's Journal of Science.)

13. Annalen der Chemie, Justus Liebig's.
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27. Bulletin de la société chimique de France. (*Before 1908 was* Bulletin de la société chimique de Paris.)
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31. Bureau of Standards, Scientific Papers.
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37. Helvetica Chimica Acta.
38. Journal of the American Ceramic Society. (*Continues* No. 81.)
40. Journal of the American Institute of Metals. *See* No. 329.
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45. Industrial and Engineering Chemistry. (*Name changed Jan. 1923 from* Journal of Industrial and Engineering Chemistry.)
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50. Journal of Physical Chemistry.
51. Journal de physique et le radium. (*Formed from* Le radium *and* Journal de physique, théorique et appliquée.)
52. Journal für praktische Chemie.
53. Journal of the Russian Physico-Chemical Society. (Chemical part.)
54. Journal of the Society of Chemical Industry.
55. Kolloid-Zeitschrift. (*Formerly* Zeitschrift für Chemie und Industrie der Kolloide.)
56. Mechanical Engineering. (*Formerly* Journal of the American Society of Mechanical Engineers.)
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81. Transactions of the American Ceramic Society. (*Continued in 1917 by* No. 38.)
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92. Zeitschrift für angewandte Chemie.
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98. Zeitschrift des Vereines deutscher Ingenieure.
100. Sprechsaal, Zeitschrift für die keramischen, Glas- und verwandten Industrien.
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106. Revue générale de l'électricité.
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244. Journal of the Society of Automotive Engineers.
248. Proceedings of the University of Durham Philosophical Society.
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255. Bulletin of the American Institute of Mining and Metallurgical Engineers. (*Continued as* No. 329.)
257. Bulletin of the Imperial Institute, London. (*Before 1903*, Imperial Institute Journal.)
258. Le cuir. Edition technique. (*Name changed Nov., 1923 to* Le cuir technique.)
259. Collegium.
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261. Journal of the American Leather Chemists' Association.
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265. Queensland Agricultural Journal.
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275. International Sugar Journal.
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291. Arbeiten aus dem Reichsgesundheitsamte.
293. Archiv der Pharmazie. (*Combined with* No. 273 *in 1924 to form* Archiv der Pharmazie und Berichte der deutschen pharmazeutischen Gesellschaft.)
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299. British Aeronautical Research Committee. Reports and Memoranda.
306. Journal of the American Society of Naval Engineers.
307. Iron and Coal Trades Review.
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309. Bulletin of the Lewis Institute, Structural Materials Research Laboratory, Chicago.
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311. France-Belgique. (Revue de l'ingénieur et index technique *merged with this in 1922.*)
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314. Tonindustrie-Zeitung.
315. Memorial des poudres. (*Formerly* Memorial des poudres et salpetres.)
317. Chemische Industrie. (*Combined with* No. 92 *in 1921; separated again in 1923.*)
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325. Proceedings of the Royal Institution of Great Britain.
329. Mining and Metallurgy. (Transactions of the American Brass Founders' Association, 1908–11; Transactions of the American Institute of Metals, 1912–16; Journal of the American Institute of Metals, 1917–18; *discontinued in 1918 and incorporated with* Bulletin of the American Institute of Mining Engineers; *with* No. 148, *1919, this Bulletin became* Bulletin of the American Institute of Mining and Metallurgical Engineers; *with* No. 154, *1919, name changed again to* Mining and Metallurgy.)
338. Researches of the Electro-technical Laboratory, Tokyo.
340. Philippine Agriculturist.
341. Journal of Agricultural Research.
342. Annales de chimie analytique et de chimie appliquée et revue de chimie analytique réunies.
343. Zeitschrift für öffentliche Chemie. (*Suspended at* end of 1922.)
344. Apotheker Zeitung.
345. Bulletin des sciences pharmacologiques.
346. Malayan Agricultural Journal. (*Formerly* Bulletin of the Department of Agriculture, Federated Malay States.)
347. Pharmaceutical Journal and Pharmacist.
348. Cotton Oil Press.
349. Seifensieder-Zeitung und Rundschau über die Harz-, Fett- und Ölindustrie mit dem Bleiblatt: Der chem.-techn. Fabrikant.
350. Les matières grasses.
351. Journal of State Medicine, London.
352. Milchwirtschaftliche Zentralblatt. (*Name changed in 1912 from* Milch-Zeitung.)
353. Academia Caesarea Leopoldino Carolina Germanica naturae curiosorum.
354. National Physical Laboratory, Collected Researches and Reports, London.
355. The Engineer, London.
356. Journal of the Royal Society of Arts.
357. Anales de la associación química Argentina. (*Name changed Jan., 1921 from* Anales de la sociedad química Argentina.)
358. Journal of the Institution of Petroleum Technologists and Record of Transactions.
359. Petroleum Age. (Petroleum; *name changed to* Petroleum Magazine, *and then back to* Petroleum; *in Sept., 1921 combined with* Petroleum Age *to form* Petroleum Age including Petroleum; *name changed back to* Petroleum Age, *Dec., 1925.*)
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361. Petroleum, Zeitschrift für die gesamten Interessen der Mineralöl-Industrie und des Mineralöl-Handels. (*Formerly* Petroleum, Zeitschrift für die gesamten Interessen der Petroleum-Industrie und des Petroleum-Handels.)
362. Chemické Listy pro vedu a prumysl.
363. Petroleum Review. (*Replaced by* No. 364.)
364. Petroleum Times. *See* No. 363.
365. Bureau of Standards, Circulars.
366. Feuerungstechnik.
367. Oesterreichische Chemiker-Zeitung.
368. Proceedings of the Institution of Automobile Engineers, London.
369. Gornyi zhurnal.
370. Memoirs of the American Academy of Arts and Sciences, Boston.
371. University Geological Survey of Kansas, Reports.
372. Verein zur Beforderung des Gewerbefleisses, Verhandlungen.
373. Chemisch-technisches Repertorium. (*Supplement to* No. 136.)
374. Oil and Colourman's Journal.
375. Polytechnisches Centralblatt.
376. Automotive Industries.
377. Bulletin de la section scientifique de l'académie Roumaine.
378. Chimie et industrie.
379. Journal of the Japanese Ceramic Society.
380. Gesundheits-Ingenieur.
381. Automobile Engineer and Internal Combustion Engineering. (Automobile Engineer, London, *1910 to Oct., 1912;* Internal Combustion Engineering, *Oct., 1912 to Jan., 1914; present name since Jan., 1914.*)
382. Refrigerating Engineering. (Transactions of the American Society of Refrigerating Engineers, 1905–13; American Society of Refrigerating Engineers Journal; *present name dates from July, 1922.*)

383. Revue générale du froid et des industries frigorifiques.
384. Le génie civil, Paris.
385. Journal of the American Society of Heating and Ventilating Engineers.
386. Canada Department of Mines.
387. Mineral Industry.
388. Översigt av Förhandlingar kongl. Svenska Vetenkaps-Akademien.
389. South African Journal of Industries. (*United with the* Official Labour Gazette of the Union of South Africa *in 1925 to form the* South African Journal of Industries and Labour Gazette.)
390. Indian Forest Bulletin.
391. Indian Forester.
392. Indian Forest Pamphlet.
393. American Society for Testing Materials Standards.
394. Fuel in Science and Practice.
395. Engineering and Mining Journal-Press. (*Formed in April, 1922 by the combining of* Engineering and Mining Journal *with* Mining and Scientific Press; *name changed July, 1926 to* Engineering and Mining Journal.)
396. Gas Journal. (*Formerly* Journal of Gas Lighting and Water Supply.)
397. Gas- und Wasserfach. (*Name changed Jan., 1922 from* Journal für Gasbeleuchtung und verwandte Beleuchtungsarten sowie für Wasserversorgung.)
398. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
399. Colliery Guardian and Journal of the Coal and Iron Trades.
400. Beama.
401. Revue de l'industrie minérale. (Bulletin de la société de l'industrie minérale; *name changed Jan., 1921 to* Revue de la société de l'industrie minérale; *name changed to* Revue de l'industrie minérale.)
402. Technique moderne.
403. Proceedings of the Institution of Mechanical Engineers.
404. Engineering News-Record. (*Formed by the combining of* Engineering News *with* Engineering Record.)
405. Glückauf, Berg- und Hüttenmännische Zeitschrift.
407. Jornal de Sciencias Matematicas, Physicas e Naturaes, Lisbon.
408. Journal de mathématiques pures et appliquées (Paris). (*Continues* Annales de mathématiques pures et appliquées; *present name dates from 1836.*)
409. Bayerisches Industrie- und Gewerbe-Blatt. (Kunst- und Gewerbe-Blatt, 1815–68; *present name dates from 1869.*)
410. Edinburgh Philosophical Journal, 1819–26; Edinburgh New Philosophical Journal, 1826–64; Quarterly Journal of Science, 1864–70; Quarterly Journal of Science and Annals of Mining, Metallurgy, Engineering, Industrial Arts, Manufactures and Technology, 1871–79; Monthly Journal of Science and Annals of Astronomy, Biology, Geology, Industrial Arts, Manufactures and Technology, 1879–85.
411. Proceedings of the North East Coast Institute of Engineers and Shipbuilders.
412. Horseless Age. (*Merged into* Motor Age *in 1918.*)
413. Journal of the Royal Aeronautical Society. (Annual Report of the Royal Aeronautical Society, 1866–96; *superseded by* Aeronautical Journal; *later* Journal of the Royal Aeronautical Society.)
414. Mitteilungen über Forschungsarbeiten auf den Gebiete des Ingenieurwesens hrsg. vom Vereine deutscher Ingenieure.
415. Journal of the Textile Industry.
416. Brennstoff-Chemie.
417. Iron and Steel Institute Carnegie Scholarship Memoirs.
418. Pottery Gazette and Glass Trade Review.
419. Ohio Journal of Science. (*Name changed Nov., 1915 from* Ohio Naturalist.)
420. Bulletin de la société d'encouragement pour l'industrie nationale.
421. Journal of West Scotland Iron and Steel Institute.
422. American Machinist.
423. Transactions of the American Foundrymen's Association. (Journal of the American Foundrymen's Association, 1896–1904.)
424. Oesterreichische Zeitschrift für Berg- und Hüttenwesen. (*Merged into* Montanistische Rundschau.)
425. Deutsche Mechaniker-Zeitung. (Beiblatt zur Zeitschrift für Instrumentenkunde.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with* Fortschritte der Physik *and* Halbmonatliches Literaturverzeichnis *to form* Physikalische Berichte.)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
429. Memoirs of the College of Science, Kyoto Imperial University. (*Before 1914 was part of* Memoirs of the College of Science and Engineering, Kyoto Imperial University.)
430. Iron Age.
431. Revue de la société russe de métallurgie.
433. Annual Report of the Royal Mint, London.
434. Scientific Transactions of the Royal Dublin Society.
435. Proceedings of the Institution of British Foundrymen.
436. Reports of the Research Department, Royal Arsenal, Woolwich.
437. Japanese Journal of Physics.
438. Transactions of the American Society of Mechanical Engineers.
439. Mémoires et compte rendu des travaux de la société ingénieurs civils de France.
440. Metal Industry and the Iron Foundry (London).
441. India Rubber Journal.
442. Annals of Botany.
443. Archief voor Rubbercultuur in Nederlandsch-Indië.
445. Zeitschrift des Vereins der deutschen Zucker-Industrie. (*Before 1898 was* Zeitschrift des Vereins für die Rubenzuckerindustrie.)
446. Zeitschrift für die Zuckerindustrie der Cechoslovakischen Republik. (*Formerly* Zeitschrift für die Zuckerindustrie in Böhmen.)
447. India Rubber World.
449. Caoutchouc et gutta percha.
450. Transactions of the Institution of the Rubber Industry.
456. Gummi-Zeitung.
459. Electrical Review and Industrial Engineer. (*Formerly* Electrical Review and Western Electrician.)
460. Deutsche Zuckerindustrie, Wochenblatt für Landwirtschaft, Fabrikation und Handel.
468. Kongliga Svenska Vetenskaps-Akademien, Handlingar.
469. Bulletin of the Institute of Physical and Chemical Research (Tokyo).
470. Memoirs of the College of Engineering, Kyushu Imperial University.
471. Army Ordnance.
472. Papier-Fabrikant (Tech.-Wiss. Teil).
473. Cellulosechemie.

B3. Landolt-Börnstein, Physikalisch-chemische Tabellen. 5th ed. Berlin, Springer, 1923.

B4. Singer, Die Keramik im Dienste von Industrie und Volkswirtschaft. Braunschweig, Vieweg, 1923.

B5. Rieke and Gary, Die Prüfung von Porzellan, 1922. Reprinted from *104*, **3**: 5; 22.

B6. Gilchrist and Klinefelter, High Voltage Porcelain Insulators. Westinghouse Electric and Manufacturing Company, Special Pub. 1690, 1925.

B7. Peek, Dielectric Phenomena in High Voltage Engineering. New York, McGraw-Hill Book Company, Inc., 1915.

B8. Rziha and Seidener, Starkstromtechnik. Taschenbuch für Elektrotechniker. 5th ed. Berlin, Ernst, 1922.

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B12. Friese, Das Porzellan als Isolier- und Konstruktions-Material in der Elektrotechnik. Klosterlausnitz, 1904.

B26. Hirschwald, Handbuch der bautechnischen Gesteinprüfung. Berlin, Borntraeger, 1912.

B27. Hermann, Gesteine für Architektür und Sculptur. Berlin, Borntraeger, 1914.

B28. Johnson, Comparison of Experiments on American and Foreign Building Stones. New Haven, Hamlen. Reprinted from *American Journal of Science and Arts*, **11**: 1; 51.

B29. Merrill, Stones for Building and Decoration. 3rd ed. New York, Wiley, 1903.

B30. Popplewell and Carrington, Properties of Engineering Materials. London, Methuen, 1923.

B31. Schweizerische Geotechnische Kommission, Die naturlichen Bausteine und Dachschiefer der Schweiz. Berne, 1915.

B32. U. S. Ordnance Department, Tests of Metals and Other Materials. Washington, Government Printing Office, 1894.

B33. U. S. Geological Survey, The Stone Industry in 1903. Washington, Government Printing Office, 1903.

B61. Ullmann, Encyclopädie der techn. Chemie. Wien, Urban and Schwarzenberg, 1914–23.

B68. Abraham, Asphalt and Allied Substances, Their Occurrence, Mode of Production, Uses in the Arts and Methods of Testing. New York, Van Nostrand, 1920.

B71. Mellor, Treatise on Inorganic and Theoretical Chemistry. London, Longmans, 1922– .

B72. Bunsen, Gasometrische Methoden. 2nd ed. Braunschweig, 1877.

B73. Berthelot, Thermochimie. Paris, Gauthier-Villars, 1897.

B74. Rieke, Das Porzellan. Hannover, 1910.

B75. Société d'encouragement pour l'industrie nationale, Contribution à l'étude des argiles et da la céramique. Paris, Chapuy, 1906.

B76. Winkelmann, Handbuch der Physik. Leipzig, Barth, 1905–8.

B77. Marks, Mechanical Engineers' Handbook. 2nd ed. New York, McGraw-Hill Book Company, Inc., 1914.

B79. de Vries, Estate Rubber. Batavia, Drukkerijen Ruycrok, 1920.